DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
S. W. STRATTON, *Director*

WAR WORK
OF THE
BUREAU OF STANDARDS

APRIL 1, 1921

MISCELLANEOUS PUBLICATIONS
OF THE
BUREAU OF STANDARDS

No. 46

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CONTENTS

INTRODUCTION

It is the object of this report to collect in one pamphlet short descriptions of some of the more important work carried on by the Bureau of Standards during the war, and which was of direct service to our military forces. It may be stated in this connection that practically all the time and energy of the Bureau's personnel were devoted to military problems during the period of hostilities, and therefore a war-work report becomes, in truth, a report of all the Bureau's activities during that time. Not all the investigations which the Bureau conducted during the war are mentioned in these pages. Unfortunately, some of the most interesting and important of them are of such a nature that for military or other reasons they can not be described. Likewise it has been impossible to cover in a comparatively short pamphlet all the investigations in which the Bureau had a part; but the more important ones (with the exceptions noted above), and those which seem most likely to result in permanent benefit not only to the military departments, but also to the industries and public, are believed to have been touched upon.

Among the most important work which the Bureau performed during the war was the examination of all sorts of plans and inventions designed to be used by the Army and Navy. The Bureau, through its cooperation with numerous governmental organizations and committees, assisted in selecting from the great mass of ideas submitted, those which appeared to possess actual value. Members of the scientific staff served on these committees, thus maintaining the closest possible contact between the committee and the Bureau. A few particular cases of this assistance are described in the subsequent paragraphs, but many have necessarily been omitted.

A great deal of the assistance which the Bureau, through its experts in all the fields of science, was able to render to our military forces came through oral advice and consultations. The value of this work can not even be estimated, and unfortunately most of it was not of a nature to become a part of the permanent records. Without doubt, a great deal of valuable time and money was often saved by the military service through informal conferences with members of the Bureau's staff.

It is hoped that those who read the following pages will find some material of assistance to them in their work, as it is the belief of this Bureau that many of the problems—the solution of

which was undertaken as a war measure—are of equal or even greater importance in the arts of peace. Their solution was one of the real benefits resulting from the war.

AERONAUTIC INSTRUMENTS

Information

From the beginning of the war the Bureau of Standards was the best-equipped organization in this country for furnishing information on the subject of aeronautic instruments. Six years of previous experience in the investigation of altitude instruments, including tests made for the United States Army and Navy, furnished the basis for a general study of the many instruments used in aviation. Much valuable material had been gathered abroad and through conferences with foreign officials who visited this country, and this was augmented by information obtained by a member of the Bureau's staff during a trip to some of the principal laboratories, factories, and airdromes in England, France, and Italy during the war. Through such means as this the exchange of information with the air services of foreign countries was facilitated.

Routine testing at the Bureau of a specified portion of the instrument production of this country was another source of information. The intimate knowledge thus obtained regarding the construction and performance of the various instruments particularly fitted the members of the staff thus engaged for making suggestions and originating improvements which many times proved to be important.

Early in the war a critical study was made of British-instrument specifications which were placed at the disposal of the Bureau of Standards by the Royal Flying Corps.

Data thus obtained were supplemented by those derived from careful tests of all suitable types of instruments which could be collected. Such information, coupled with the results of a survey of the manufacturing facilities of this country, enabled the Bureau to render expert assistance in writing specifications and advising in regard to instrument production. As a result of this preparation, the performance specifications, and in some cases the construction specifications also, for all instruments adopted as standard by the Army and Navy during the war were based directly on technical information obtained at this Bureau.

The early work of the Bureau of Standards in studying altitude instruments and in assisting to start the production of aeronautic

instruments made it natural that the military and naval authorities should turn to the Bureau for information whenever questions arose in any phase of the instrument work. Much information and advice was given out in reply to official correspondence and to verbal requests. A considerable part of this consisted of examining and reporting on inventions relating to aeronautic instruments and other appliances submitted by the General Staff of the Army and by the National Advisory Committee for Aeronautics. Members of the staff were called on frequently for conferences with visitors. During the summer of 1918 production officials of the Army and Navy visited the Bureau practically every day to follow the results of investigations or to discuss specifications in connection with instruments.

To make information more readily accessible and to provide for a simple means of distribution in the proper channels, a series of confidential technical information circulars was issued covering various phases of the instrument work. These met with immediate and continually increasing demand, as they constituted the first attempt of this nature to satisfy a pressing need. Distribution abroad created a demand among the foreign air services for this material. A large number of the circulars have been furnished British, French, and Italian officials, and it is understood that in many cases translations have been made. A number of these circulars contained confidential information from the allied Governments which, together with the necessary secrecy surrounding all developments during the war, made it imperative to limit their circulation to official circles. The close of hostilities makes it probable, however, that they will be made available for more general distribution as fast as permission can be obtained to release the foreign material.

Altitude tables which were used in calibrating the dials of all altitude instruments were calculated at the Bureau of Standards and were furnished to the manufacturers. In addition, tables of temperature corrections for altitude instruments and altitude corrections for air speed indicators were computed.

Valuable and much-needed information was given to the various manufacturers regarding suitable testing methods and apparatus to be used in the testing. Also from time to time many useful suggestions were made regarding the best methods of manufacture and the proper materials to use.

Another important part of the Bureau's work consisted in furnishing to the Army and Navy information regarding the

proper use and repair of instruments. At the request of the Navy Department, a school was conducted at the Bureau of Standards for naval aviators. An intensive course covering the theory, testing, and use of aeronautic instruments was thus provided. In addition information was furnished directly to the flying fields and salvage stations of the American Expeditionary Forces regarding the testing and proper use of instruments.

Testing and Investigation

The starting of aeronautic instrument production in this country necessitated immediate preparation for testing the instruments. It was necessary to control the quality of the output by frequent tests more thorough than the acceptance tests given by the inspectors at the factories. To this end provision was made to have the Bureau of Standards give thorough laboratory tests to 4 per cent of the total production. For this purpose the design and construction of suitable testing apparatus was rapidly carried out. This apparatus included temperature chambers and vibration stands, so that the instruments might be subjected to the same conditions as would be encountered in actual use.

To facilitate testing at the factory the Bureau developed modifications of its laboratory tests for acceptance purposes and instructed the Government inspectors in these methods of testing. In a number of cases the Bureau calibrated manufacturers' standards and even constructed standards and loaned them to manufacturers.

Investigations were made on different occasions to determine the causes for the failure of instruments to function properly. For instance, at one time the Bureau's tests on altimeters showed consistently poor performance. A careful study showed that this was due to the rusting of the small, steel chain which operates the pointer. This discovery led to the rejection of 5,000 instruments which had already been accepted by the Air Service. Along the same line tests showed that most of the breakdowns which occurred in a certain type of tachometer were due to a faulty type of escapement. The latter was changed to a sturdier type, and the durability of the instrument was much improved.

The laboratory tests on large quantities of instruments were naturally very important as a source of information regarding the average performance of different types. The long-continued investigation of such instruments as altimeters, airspeed indicators, oxygen apparatus, and tachometers has furnished statistics

which are and will be in the future of considerable value to the scientific and engineering world.

Although complete laboratory tests indicate quite accurately the quality of an instrument, the performance of the latter during flight tests will often reveal defects which would not be indicated in the laboratory. Consequently, flight tests were made by members of the Bureau's staff with a view to noting peculiarities in the performance of different instruments. To mention a specific case, laboratory tests on a certain liquid manometer type of rate-of-climb indicator gave most satisfactory results. However, when the instrument was tested in flight the combined effect of acceleration and inclination caused such fluctuations of the liquid column as to make the readings of no practical value. Improvements were immediately suggested owing to the discovery of this fact which might not have been brought out so forcibly had only laboratory tests been made. In such a manner laboratory data were supplemented by flight data, and an extensive knowledge of the performance of the instruments under all conditions was obtained.

Development

The first aeronautic instruments submitted for test, with the exception possibly of altimeters, were in a more or less elementary stage of development. The data gained from these tests suggested improvements which could be made, and thus the instruments were gradually developed.

As aviation progressed, new instruments were needed; for example, oxygen-control apparatus for furnishing a regulated supply of oxygen to the aviator at high altitudes, rate-of-climb indicators for giving the vertical component of the speed, and an automatic means of taking instrument readings during performance tests.

The Bureau of Standards took an active part in the development of oxygen apparatus in the United States by promoting cooperation between the foreign experts and American manufacturers in order to get production started. Valuable suggestions were made looking toward the elimination of defects and improvement in the performance of the instruments after careful tests had been carried on at the Bureau. A new feature designed to avoid the main source of temperature error was developed.

The necessity for measuring accurately the speed of ascent in performance tests created an urgent demand for an instrument

which would read this quantity directly. The inherent errors in the liquid-manometer, rate-of-climb indicator, made it desirable that a new type of instrument be developed, using some means other than a liquid column as a pressure measuring device. The Bureau of Standards consequently undertook the development of a rate-of-climb indicator whose indications depended on the deflection of very sensitive diaphragm boxes. This instrument was nearly completed at the end of the war and gave promise of being an improvement over former types.

As high-altitude flights became more common the need of barographs capable of recording such altitudes became more acute. At the request of the flight-test officers, several 10 000-foot barographs were remodeled to give a 30 000-foot range, according to a method developed at this Bureau.

For some purposes it is more convenient to have the pressure of the atmosphere indicated instead of the altitude. On this account a number of altimeters were remodeled and fitted with special dials to meet this need.

Detail drawings of a gyrostabilizer for instruments had been prepared at the time of the armistice and a working model of about one-fourth size constructed. A bomb sight and double-pivot compass to go on the stabilizer formed a part of the design.

A new type of inclinometer or banking indicator for use in determining the position of the aircraft relative to the proper banking angle was developed. Actual tests showed the instrument to be practical and to possess advantages over those ordinarily in use.

The instrument differed from the ordinary bubble-type of banking indicator in having, instead of a bubble, a carefully ground glass ball, the inside of which was coated with a self-luminous paint. This ball was mounted inside of a curved glass tube mounted convex downward on an angularly graduated base. The position of the ball in the tube indicated the position of the aircraft relative to the proper banking angle. The instrument could be easily read without artificial illumination.

The importance of securing accurate records of aircraft performance tests led a member of the Bureau's staff to consider using the principle of the motion-picture camera to obtain a continuous photographic record of the instrument board during flight. It was recognized that the development of such a device would be an improvement in many ways over the use of recording

instruments. Later a similar suggestion was received from Maj. R. W. Schroeder, and plans were made for development of such a "dummy observer," as it was called, and the apparatus was constructed subsequent to the signing of the armistice.

Instrument Collection

The Bureau of Standards possesses one of the most complete collections of aeronautic instruments in the world. Not only samples of practically every kind of airplane instrument made in this country, but all kinds of foreign instruments, as well, were obtained during the war. A collection of typical instruments which the Bureau prepared for exhibition purposes is shown in Fig. 1.

The original purpose of the collection was to aid in instrument production by making available for the manufacturer types of foreign instruments with which he had had no experience. In several cases production was facilitated at the beginning of the war by the copying of instruments thus made available by the Bureau of Standards. Later, as it grew, the collection became useful for instruction and investigation purposes. The great variety of American, British, French, Italian, and German instruments included make it one of the most useful collections for reference and comparison in existence.

Magnetic Compasses

This subject will be found to be treated under the heading, "Magnetic Investigations."

AERONAUTIC POWER PLANTS

Description of Altitude Laboratory

The part played by aircraft in the war was of the first importance, and at the time the United States entered the conflict it was apparent that the victory was likely to go to the side having the largest number and most efficient types of machines. It therefore became the duty of the Government to make a thorough study of the aeronautic situation with a view to improving, wherever possible, the performance of airplanes and their appurtenances. Since the success of an airplane depends very largely upon the operation of the power plant, a study of aeronautic-engine performance on a larger scale than anything before attempted was decided upon. As a consequence, in cooperation with the National Advisory Committee for Aeronautics, the Bureau constructed what has since become known as the altitude laboratory for the

FIG. 1.—*Group of typical aeronautic instruments*

The bureau has assisted the aviator by supplying him with more reliable indicating devices, the sense organs of an airplane

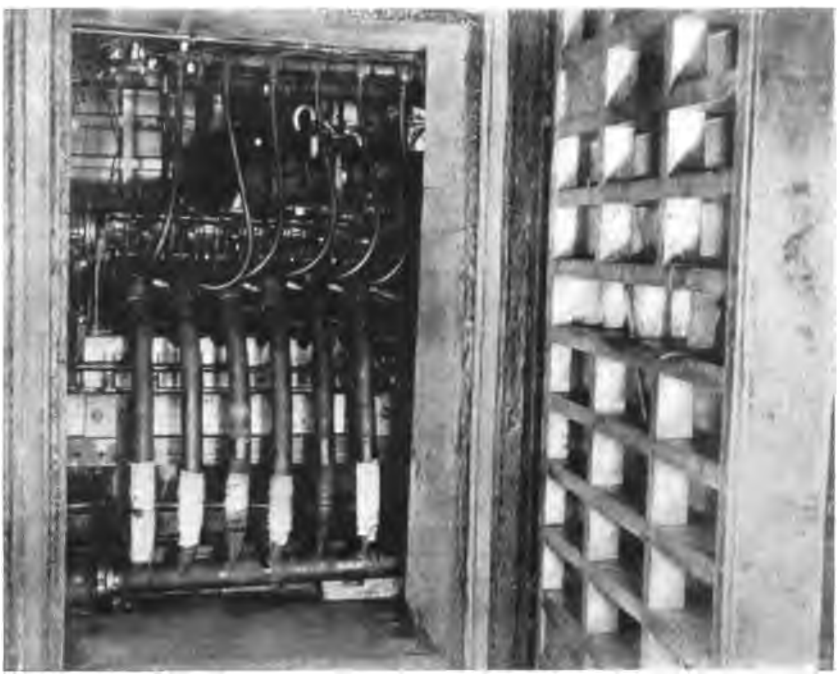

FIG. 2.—*The "Liberty 12" airplane engine mounted in the altitude chamber*

When the doors (one of which is shown at the right) are closed this chamber is practically air tight. The air pressure and temperature are then lowered to those corresponding to any desired altitude, and the engine tested under actual flying conditions

FIG. 3.—*The carbureter test plant*

This plant is specially designed to test airplane carbureters under altitude conditions. Even the pulsations in the inlet manifold caused by the pumping action of the engine's cylinders are duplicated in this apparatus

testing of aircraft engines as nearly as possible under service conditions. Since its construction, the laboratory has been in almost continuous operation and results of the greatest possible value, not only in the field of aeronautics, but to the automotive industry in general, have been secured.

It is perhaps not generally known that the laboratory testing of aircraft engines presents peculiar difficulties not met with in the case of other types of internal-combustion engines. These difficulties are due to the fact that the engine of an aircraft performs most of its work not at the earth's surface, but at altitudes ranging from a few thousand to 30 000 feet. Atmospheric conditions at the higher altitudes are very different from those at the earth's surface, the pressure of the air at 30 000 feet being less than one-third that encountered at sea level. The average temperature at such an altitude is in the neighborhood of $-35°$ F, and both the atmospheric density and temperature have a pronounced effect upon the operation of an internal-combustion engine. The amount of explosive charge which the engine is capable of drawing into its cylinders varies with the density of the air, which, of course, is a function of altitude. Temperature is also a controlling factor, and, besides affecting the quantity of the charge, produces numerous other variations in the operation of the engine, such as those brought about by changes in the temperature of the jacket circulating water, lubricating oil, etc.

When it was decided to conduct a thorough investigation of airplane-engine performance, it was apparent that the laboratory must be so designed that the entire engine could be surrounded with conditions existing during an actual flight. Time has shown that this decision was a correct one, but it meant the construction of a laboratory unlike anything before attempted. The essential features of the altitude laboratory consist of a concrete chamber, the walls of which are of such thickness and so reinforced that they are capable of withstanding a considerable pressure from without. Within this chamber, the engine is mounted on a stand designed to duplicate as nearly as possible the typical airplane-fuselage mounting. The chamber is provided with doors on opposite sides, so that the interior may be easily reached, but these doors are arranged to close upon rubber gaskets, so that when shut they form an airtight joint. The exhaust from the engine and the air within the chamber are withdrawn by means of a centrifugal exhauster driven by an electric motor so that the

pressure within the chamber may be reduced as low as one-third of an atmosphere, or that corresponding to an altitude of about 35 000 feet. Fig. 2 is a view of the Liberty 12-cylinder engine set up in the chamber.

The air supply to the carbureter first passes over a series of refrigerating coils by which its temperature is lowered to a point approximating that met with at the altitude of the test. Similar coils within the chamber keep the air surrounding the engine at about the same temperature, and electric fans cause a circulation somewhat similar to that met with during a flight. These coils for cooling the air form part of an ordinary direct-expansion ammonia-refrigerating plant. Since the temperature of the air can not be controlled very readily by means of the refrigerating plant alone, electric-heating grids are placed within the air passage to the carbureter so that in practice the temperature of the air is first lowered by the ammonia coils and then raised slightly by the electric grids to the exact temperature desired. The engine is connected by a coupling and shaft, passing through an air-tight stuffing box in the chamber wall, to an electric dynamometer and water brake, by means of which its power is absorbed and measured. Thermocouples are placed at all points at which temperature measurements are desired, and manometer tubes are connected to the engine and piping systems to measure the pressures. These are all led to convenient points outside the chamber. The fuel used is weighed by tanks mounted on scales on a platform sufficiently high to insure a flow of fuel to the engine by gravity.

The exhaust from the engine is water cooled, the water entering the exhaust pipe at some little distance from the engine, so as not to affect the operation in any way. This water is removed from the exhaust gas in what may be termed "settling tanks" placed outside the chamber. From these tanks the gases are removed by the exhauster, mentioned above, while the water is drained by gravity, the drop of the pipe being sufficient to prevent any breaking of the vacuum.

The altitude laboratory as originally constructed and operated during the war consisted of a single chamber placed in a temporary wooden building. This has now been replaced by an installation of two chambers in the permanent dynamometer laboratory of the Bureau. The arrangement is such that the chambers may be used either separately or together; that is, communicating doors

may be thrown open and both sets of pumping equipment used to remove the air and gases from a single engine. In this way the capacity of the plant will be greatly increased.

Operating Conditions Studied in the Laboratory

The problem first presented by the National Advisory Committee for Aeronautics for solution by the use of the altitude laboratory was that of the performance of different grades of gasoline at high altitudes in typical aircraft engines. The lubrication division of the Signal Corps requested also the preservation of samples of the lubricating oil to determine the effect of fuel composition and of altitude on the deterioration of such oils. A staff of two or three men was detailed by the lubrication division to assist in securing the desired data.

As different grades of fuel (all of comparatively high quality) affect engine power and performance only to a very slight extent, the satisfactory solution of this problem required the highest possible accuracy in obtaining complete data on engine performance as previously outlined. Thus a practice was established by which all the measurements of power, speed, fuel consumption, barometric pressure, air and water flow, temperature, and pressure provided for by the apparatus are customarily made, no matter what is the immediate purpose of the test in hand. The result is, in addition to the data directly desired, an accumulation of valuable supplementary data on engine performance.

Observations have been made to determine specifically the following relations:

1. Horsepower-altitude relation for engines at normal speed.

2. Horsepower-speed relation at a range of altitudes up to 30 000 feet.

3. Horsepower-compression ratio for normal speed, using compression ratios of 4.7, 5.3, and 6.2 to 1 at a range of altitudes up to 30 000 feet.

4. Horsepower-inlet air temperature at a range of speeds and altitudes.

5. Effect of variation of intake pressure on horsepower at a range of altitudes to simulate the effect of supercharging equipment.

6. Effect of exhaust back pressure on horsepower over a limited range of pressures.

7. Mechanical losses at various speeds, altitudes, and engine temperatures.

8. Metering characteristics of a number of different types of carbureters with and without altitude compensation or control for the full range of speeds and altitudes.

9. Optimum mixture ratios for maximum power over the range of speeds and altitudes with several different carbureters.

10. The performance of a number of automatic and hand-operated altitude-compensation devices for different carbureters.

11. The total heat distribution for all speeds and air densities at full throttle.

12. The performance of special fuels: "Hector," a combination of cyclo-hexane and benzol; "Alco-gas," a combination of alcohol, benzol, gasoline, and ether at a compression ratio of 7.2 to 1.

Other relations have been investigated from time to time. Moreover, the detailed records taken for each test include much information bearing on other characteristics of engine performance, such as, for instance, the behavior of spark plugs and ignition systems under conditions of low-air pressure and temperature.

Carbureter Performance as Affected by Altitude

In addition to the altitude laboratory the Bureau has constructed a complete plant for the testing of aeronautic carbureters, and in cooperation with the National Advisory Committee for Aeronautics has carried on an extensive investigation of these devices. The performance of carbureters under the conditions existing at high altitudes, where air density and temperature are low, is a matter of great importance and affects markedly the operation of airplane engines. The carbureter test plant is made up of a strongly constructed box of wood and metal with a glass door within which the carbureter is mounted. The opening in the carbureter which would ordinarily be connected to the inlet manifold is coupled to a pipe leading to a centrifugal exhauster driven by an electric motor. A shutter is placed in this pipe and connected by step pulleys with a small motor, so that it may be driven at any desired speed and thus simulate the conditions of pulsating flow encountered in an actual manifold. Air is admitted to the inclosed chamber through a metering orifice and regulating valve, and its temperature may be raised above that of the surrounding air by means of electric heating grids. Fuel is fed to the carbureter from a weighing tank and automatic devices are provided for recording the consumption in a given time. The construction of this plant is clearly shown in Fig. 3. With this plant complete investigations have been carried out on all the

ordinary styles of airplane carbureters, and their metering characteristics have been determined over the range of altitudes likely to be encountered in actual service. The plant was not designed and has not been used to eliminate the engine testing of carbureters, which will always be the final determining factor, but the preliminary work may be done on the carbureter-test plant much more rapidly and cheaply and with far greater accuracy than on an engine. With the test plant all undesirable variables may be omitted and only those factors changed which it is desired to study.

Aircraft Cooling Radiators

In connection with the work on aeronautic power plants, the Bureau of Standards has conducted for the past four years an extensive investigation of the performance of airplane radiators. The efficient functioning of the cooling system is an extremely important matter in the case of aircraft engines, since any form of radiator offers some head resistance and must take away a portion of the power of the engine which would otherwise be available for driving the plane, while at the same time a radiator of high cooling capacity is needed, owing to the fact that aviation engines are generally run at their maximum power for long periods of time. The ideal radiator for airplane use is, therefore, one with a large cooling capacity and low head resistance (not necessarily for the radiator alone, but for the combination of plane and radiator), but these two requirements are in general contradictory.

This subject became of extreme importance when the United States entered the war, and shortly thereafter the Bureau undertook, in cooperation with the National Advisory Committee for Aeronautics, a complete investigation of the relative merits of existing types of airplane radiators. Since that time, tests have been made on nearly all makes of radiators now in use, and the results have been correlated and issued for the benefit of those interested, through the reports of the above-mentioned committee. Specimens of the various standard radiators were submitted by the manufacturers. These were all constructed to certain given dimensions of height and width, but the sizes of the air and water tubes and the depth of the core were those which would be used in the actual radiators. In this way, all the tests were reduced to a common basis, only those peculiarities which were due to the design and not to the size of the radiator having an effect on the result.

The investigational work carried on in this connection falls naturally under two heads: (1) The determination of the head resistance of the radiator core, and (2) the determination of the efficiency of the radiator as a cooling device. The first property was investigated by mounting the specimen of radiator core upon the vertical arm of an aerodynamic balance in one of the Bureau's wind tunnels. Air streams of various known velocities were caused to impinge on the specimen, and its head resistance could therefore be easily determined. In these tests the bare core without water boxes was used. Experiments were likewise conducted to determine the relative head resistances of a model fuselage with stream-line nose and radiator mounted in an open position on the plane and that of the same fuselage with a nose radiator, such as has largely been employed on modern machines. The results of this investigation were of particular interest as showing the very large amount of power absorbed by nose radiators. Although this position possesses certain advantages, particularly in the case of airplanes designed for use in warfare, it would appear to be a very poor position for the radiator from the point of view of head resistance.

Two methods were used for determining the efficiency of a radiator as a cooling device. In the simplest of these, the radiator was mounted in a tunnel through which an air stream was forced. At the same time superheated steam at atmospheric pressure was admitted to the water space of the radiator and the amount of steam condensed in a given time with a given air flow determined. The radiator which would condense the greatest amount of steam in a given time was, of course, the most efficient cooling device. The other method used consisted in mounting the radiator in a tunnel, the whole of which was inclosed in an air-tight tank. The pressure within this tank could be reduced to that corresponding with any desired altitude up to about 35 000 feet, while at the same time the air was circulated through the radiator by a fan driven by belt from an electric motor. The same air constantly passed through the radiator, but was cooled by a honeycomb on the other side of which water was circulated. In these tests water, and not steam, was used in the radiator.

The tunnel, just now described, was the one originally used in carrying out the investigation of radiator-cooling capacity, but owing to the fact that a very long time was required for establishing stable conditions within the tank, the steam tunnel was finally

used, as it was found that it gave just as satisfactory comparisons between different types of radiators.

As a result of this work it has been possible to state with accuracy the percentage of the total available horsepower of an airplane engine which any given type of radiator will absorb and also the efficiency of the radiator as a cooling device. Fundamental data have been collected, and the Bureau has been able to indicate certain general features which should be observed in the design of a successful radiator for airplanes.

Airplane-Engine Fuels

From the beginning of the war the work of the Bureau of Mines on automotive-fuel conservation was actively supported by the Bureau of Standards through close and constant cooperation. At the meeting of the Interallied Commission on Specifications for Petroleum Products of the Interallied Petroleum Conference some of the foreign delegates urged a very rigid gasoline specification for fuels for use in combat aircraft, basing their recommendations on their own satisfactory experience with certain gasolines, but without full knowledge of the possible performance of other gasolines. The adoption of such close specifications would have materially reduced the available supply of combat aviation gasoline and introduced unnecessary expense and serious difficulty, not only in production but in overseas shipment and distribution. A careful comparison of the power-producing qualities of 10 different gasolines selected through cooperation with the Bureau of Mines was made by actual engine tests under flight conditions in the altitude laboratory of the Bureau. A report on these tests was the only quantitative data presented to the interallied commission on this subject, and it resulted in the adoption of more liberal gasoline specifications, which were amply justified in service and which resulted in a saving to the American people of millions of gallons of oil in their fields and thousands of dollars waste effort in the refining and distribution in France of aviation gasoline.

In connection with the work on aviation fuels, a thorough study was made of the best methods for determining the quality of gasoline. It is generally recognized that the simplest test, that for gravity, does not give a reliable indication of the value of gasoline as a fuel. On this account tests were made of the viscosities of various commercial and aviation gasolines, in the hope that this property might prove to be of value, in connection with others, in specifying the quality of fuels. It was found that the

viscosity has a marked influence on the metering characteristics of carbureter nozzles, and must be taken into account. A thorough discussion of this subject will be found in Technologic Paper No. 125, "The Viscosity of Gasoline."

In addition to service tests on common and aviation gasolines, a number of synthetic fuels were tested at the request of the Bureau of Mines and the Navy Department, respectively. Reports were prepared on the performance of "Hector" fuel, a mixture of 70 per cent cyclohexane and 30 per cent benzol developed by the Bureau of Mines, and "Alcogas," a fuel containing a large percentage of alcohol. The general conclusions from these tests will be compiled for publication. Five proprietary preparations intended to be used as gasoline substitutes were tested for the military service. Many of the so-called "gasoline improvers" were tested for the inventions section of the General Staff of the Army. Two devices for the convenient use of kerosene instead of gasoline in the usual gasoline engine have also been tested for this section.

Ignition Systems

In November, 1916, the National Advisory Committee for Aeronautics requested the Bureau of Standards to undertake a study of the causes of failure of spark plugs, and to develop, if possible, a new insulating material which would be superior to those then available for use in such devices. This request was the result of reports from abroad which indicated that spark-plug trouble was one of the limiting features in the design of the most recent high-power aviation engines. A program was laid out according to which the Bureau's ceramic laboratory was to prepare a number of samples of porcelain of widely different composition. These were to be tested by the electrical laboratories for their relative merits, and on the basis of these results further porcelains were to be made up until a satisfactory material was found.

The early experiments indicated a great need for more information as to the conditions under which spark plugs were required to operate, and when the more general program for the study of all phases of aeronautic power plants was begun at the Bureau the ignition investigation was enlarged and fitted in as one of the principal divisions of the program. The ignition staff was enlarged, and during the latter part of the work consisted of seven persons; the work included a study of the conditions in aviation engines and the measurements of the various constants of ignition systems, as well as the development of materials.

Throughout the work intimate contact was maintained with officers of the National Advisory Committee for Aeronautics and the Bureau of Aircraft Production, and much of the testing was at the direct request of the inspection section of this latter bureau. Owing to the frequent and unavoidable changes in organization of the branches of the War Department connected with aviation during the war, it was found difficult to obtain data as to the actual service performance of the various spark plugs and ignition systems in use at the flying fields.

The duty of the ignition system is to produce at the proper time in the interior of the combustion space of gasoline engines a spark which, by igniting the compressed mixture of gasoline, vapor, and air, causes it to burn and deliver its energy to the engine. All of the systems in practical use on high-speed engines are of the jump-spark type. The essential feature of the system is an induction coil, which consists of an iron core upon which is wound a primary coil of few turns of relatively large wire and a secondary coil having a very large number of turns of fine wire. A current is established in the primary winding either by means of a battery connected in series with the coil, as in the case of so-called battery and coil systems or else by inducing current magnetically in the primary coil by the relative motion of the coil and of a permanent magnet, as is done in the case of magnetos. With either type of system when a spark is desired in the engine, the circuit breaker is suddenly opened by means of a cam and the magnetic flux produced by the primary current rapidly decreases. This decrease in flux generates in the many turns of the secondary winding a high voltage which is conducted from the distributor to the spark plug in the proper engine cylinder. The current passes across the spark gap at the plug to the grounded electrode and returns through the engine frame to the other end of the secondary coil.

There are two essential operating characteristics of this type of apparatus which must be borne in mind in considering its behavior under various adverse conditions. First, with the secondary circuit open the voltage will build up to a certain maximum value (10 000 to 20 000 volts) which is determined by the inductance and capacity of the circuits, and no spark will be produced unless the breakdown voltage of the gap between the spark-plug electrodes is less than this value. The length of the spark gap usually used in aviation engines is such as to break down at about 6000 volts, thus affording in this respect a factor of safety of two or three. Second, if the spark plug is shunted by a resistance, the

maximum voltage obtained across its terminals is very considerably reduced, the reduction being greater as the shunting resistance becomes less. With most ignition systems, the voltage reached becomes less than the 6000 volts required to produce a spark when the shunting resistance is less than 100 000 ohms. It is, therefore, the duty of the spark plug to perform three functions: (1) To maintain a gap between its electrodes which shall have a breakdown voltage of approximately 6000 volts; (2) to maintain an insulation resistance between its terminals of not less than 100 000 ohms; (3) to be substantially gas-tight in order that the leakage of heated gas through the plug may not raise it to such a high temperature as to cause preignition of the engine and destruction of the plug. These requirements can be met with comparative ease in spark plugs used in automobile engines, but the conditions of operation in the modern aviation engine, where every effort is made to obtain high powers with small space and weight, are very much more severe.

Measurements which have been made at the Bureau in aviation engines show that the pressures attained may amount to 500 to 600 pounds per square inch, and the difficulty of maintaining gas-tight joints is very great. Also, experience has shown that the mechanical vibration of even well-balanced engines is often sufficient to crack the porcelain insulation. During a cycle of operation of the engine the spark plug is alternately exposed to a blast of cold air which during the intake stroke may be at a temperature well below zero, and is immediately thereafter exposed to the flame of compressed and burning gasoline vapor, the temperature of which may be estimated at 2500° C. These severe temperature conditions tend to crack the porcelain, and by the expansion of the parts, to open up cracks for the leakage of the gas. Moreover, refractory materials of the class used for spark-plug insulators (mica, porcelain, glass, etc.) become conductors of electricity if heated to a sufficiently high temperature.

In addition to the trouble just mentioned, the flame of burning gasoline deposits a layer of soot on any cold surface with which it may come in contact, and, furthermore, the lubricating oil which is present in the cylinder may be sprayed against the heated portion of the spark plug and, decomposing, also leave a layer of carbon. These carbon deposits tend to short-circuit the plug and may reduce its insulation resistance below the limiting value. Another type of failure is produced if the surface of the electrodes becomes covered with lubricating oil, or more particularly, if a

drop of oil bridges the gap, since this oil before being decomposed has a breakdown strength of from 10 to 15 times that of air. The voltage required to produce a spark across the gap is much increased and may exceed the value which the ignition system can deliver.

The aim in spark-plug construction is to satisfy as completely as possible the three requirements of definite spark voltage, high insulation resistance, and gas tightness by suitable modification of design or material, while the aim in ignition-system design is to reduce as much as possible the stringency of these requirements.

The ignition staff of the Bureau has endeavored to assist the military departments of the Government in ignition problems: (1) by making such measurements and tests of commercial apparatus as were requested by the departments concerned, in order to determine the relative and absolute merits of devices then on the market; (2) by devising new methods of test to show more clearly such relative merits, and preparing specifications based on these tests; (3) by collecting as much information as possible as to the dimensions, constants, and performance of various types of systems in order to be able to give more intelligent advice on the subject: (4) by assisting various manufactures of ignition apparatus, by tests and consultation, in their development of materials and designs which showed promise of success; (5) by studying the conditions under which such apparatus operates on aviation engines and thus securing data otherwise unobtainable by individual manufacturers; and (6) by developing in the Bureau's laboratories improved materials and better arrangements of circuits. The following paragraphs outline in more detail the results of these various lines of work.

The program for the development of improved insulating material mentioned above has been carried out with the result that several porcelains have been obtained which show very excellent properties as regards electrical resistance while hot, resistance to cracking when exposed to sudden temperature changes, and mechanical strength. The composition of these materials has been given to various porcelain manufacturers requesting it, and it has been put into production by the largest spark-plug manufacturer in the country. The method of measuring resistivity used in this development work has been adopted by a number of manufacturers for their own laboratories, and others have submitted samples of their product to the Bureau for test. One of these materials, which had hitherto been used only to a slight extent in spark

plugs, showed very satisfactory results when subjected to the Bureau's tests, and, as a result, has been adopted by several of the principal spark-plug manufacturers.

It was necessary in the work to devise various methods of testing spark plugs. In addition to the conductivity measurements developed for the porcelain testing, methods have been devised for testing the resistance of the insulating material to sudden changes of temperature and to mechanical shock, and a quantitative method has been developed for measuring the gas tightness of the plugs while they are heated as in an engine. Methods have also been developed for measuring the heat energy in the spark produced by various types of ignition systems and for determining the ratio of turns and the magnetic leakage between the primary and secondary coils of such systems. A general view of the spark-plug laboratory showing most of the apparatus used in these investigations is given in Fig. 4. The performance of ignition systems as to the maximum voltage obtainable and the minimum resistance across which they can produce a spark seems to depend in a very large degree upon the amount of eddy current which may be produced in the iron core and upon the electrostatic capacity of the various parts of the circuits. No methods are at present known for conveniently determining these quantities, but the Bureau is still engaged in developing a method which, it is hoped, will provide a satisfactory measurement of these important properties.

At the request of the Bureau of Aircraft Production and of the Motor Transport Corps, specifications have been prepared on the basis of which they may purchase their spark plugs, and the tests developed at the Bureau have been incorporated in these specifications.

A very considerable amount of testing of spark plugs of various designs and of proposed types of ignition systems has been carried out at the request of the inspection section of the Bureau of Aircraft Production. (See Fig. 5.) The results have been reported in detail to this section and to the manufacturers of the particular products tested. These tests, together with those incident to the development of the Bureau's methods and the study of spark plugs obtained from various foreign sources, have brought up the total number of spark plugs on which records have been kept to over 3 000, among which over 100 distinctly different types are represented.

FIG. 4.—*A corner of the spark-plug laboratory*

At the right are the two electric furnaces used in measuring the electrical resistance of various porcelains, using samples in the form of cups, as shown near the furnaces. The instruments used in the measurements are shown in the center, while at the left are the pressure tanks and glass bell jar for measuring gas leakage through plugs. In the rear are sample plugs and porcelain cups submitted for test

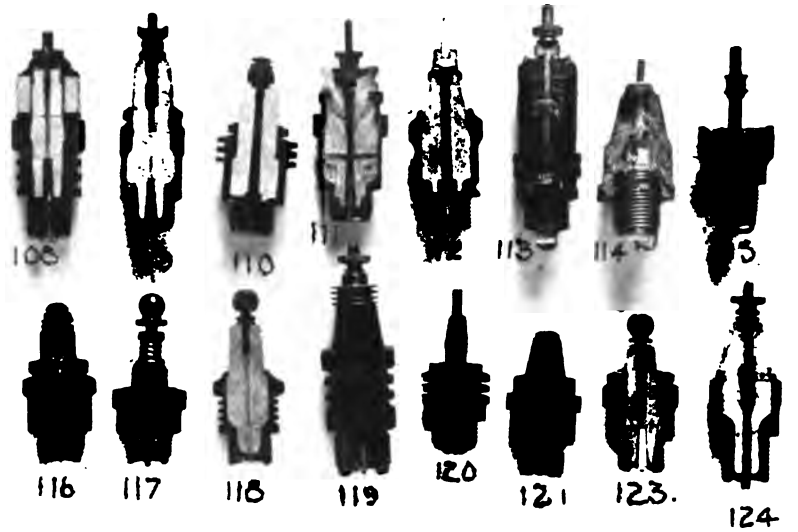

FIG. 5.—*Cross-sections of typical aviation spark plugs*

That no one design has yet proved entirely satisfactory is evident from the variety of constructions shown here. All these plugs have been tested

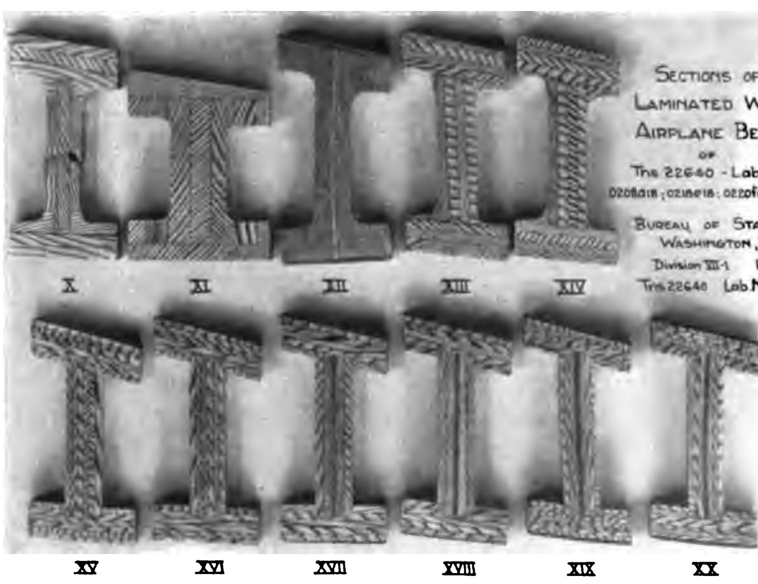

FIG. 6.—*Cross-sections of laminated wooden airplane beams*

This form of construction permits the use of smaller pieces of high-grade wood as well as inferior woods in the building of airplanes. The strength of these laminated beams is just as great as that of solid beams

Measurements have been made of the temperatures existing in various parts of spark plugs when operating in aviation engines, and these results have formed the basis for the other testing work just mentioned. There is still much need for further work to see how these temperatures vary with the type of plug and engine used.

At the request of the Bureau of Aircraft Production, extensive oscillographic tests were made on 12 different types of ignition systems. This method of test shows photographically the current in both the primary and secondary coils at each instant throughout the operation of the system and can be made to show the short-circuit current and open-circuit voltage of the magnetos and the behavior of the circuit breaker. The photographic records obtained give a complete account of the performance of the apparatus and the values of current, voltage, etc., can be read off at leisure. Copies of the records were sent to the various branches of the War Department interested, and the large mass of data contained in them was correlated by the Bureau as time permitted, and the results have been published in the Fourth Annual Report of the National Advisory Committee for Aeronautics.

In connection with the oscillographic test, other electrical constants of the ignition systems, such as the inductance, capacity, resistance, and the heat energy in the spark, were observed on a variety of systems, both to determime their relative merits and to serve as a basis for possible improvements in the design of such apparatus. It is hoped to continue the testing of a variety of systems in order that the fundamental data may be obtained and published for the benefit of American manufacturers.

Another distinct part of the ignition work has been the study of the use of subsidiary spark gaps which frequently have been proposed as an improvement over the usual types of ignition systems. These devices have the advantage of enabling a system to produce a spark even though the plug may be shunted by a resistance decidedly less than the limiting value of 100 000 ohms stated above. The manufacturers of these devices, however, frequently have made exaggerated claims as to their merits, and the work at the Bureau was undertaken with a view to determining to what extent these claims are justified and to obtaining definite information as to the possibilities and true performance of this type of device. It has been found that the claims of increased power and efficiency are unwarranted, but that the device has the very definite merit of causing a fouled plug

to fire, since an engine has been made to fire continuously although the plugs were fouled with a resistance of only 5000 ohms.

The rubber-insulated cables connecting the spark plugs with the distributer occasionally give trouble as a result of the cracking of the insulation. This is a progressive deterioration which occurs where the cable is sharply bent, and after continued exposure to the high voltage electric stresses incident to the operation of the system. The Bureau of Aircraft Production asked that the precise reason for this cracking be determined, and a series of experiments was carried out which demonstrated conclusively that the cracking was the result of a chemical reaction between the rubber and the ozone formed by the high-voltage electrical discharges which occurred at the surfaces of the cable. This reaction is localized in cracks whenever the rubber is subjected to mechanical tension. The remedies suggested are the use of a thoroughly impregnated braid, the avoidance of sharp bends in the wiring, and the use of such rubber compounds as are least affected by ozone.

The results of the various lines of work mentioned above were issued in a number of separate reports which formed a part of a series on aeronautic power plants. These reports were distributed by the Bureau to a limited mailing list made up of those officers of the War and Navy Departments interested, and, where no data of a confidential nature from a military or commercial point of view were involved, to manufacturers and other persons interested.

These reports were all published at a later date in the Annual Reports of the National Advisory Committee for Aeronautics.

Lubrication of Aircraft Engines

Although the matter of the satisfactory lubrication of aircraft engines was admitted to be one of great importance, it was not until several months after the United States entered the war that a definite investigational program of this subject was commenced. Before the beginning of actual experimental work, representatives of the Bureau visited various aviation fields and obtained more or less complete data on the oils in use. Samples of new and used oils were obtained and were later analyzed in the laboratory. A conference was also held with one of the members of the Council of National Defense, and the subject of lubrication was thoroughly discussed. The results of this preliminary work showed that no one kind of oil was in use at all the fields, and that even at the

same field contradictory opinions were held respecting the merits of various brands.

In October, 1917, the Bureau was asked to cooperate with the Signal Corps in testing airplane lubricants. By agreement the Bureau made certain tests of a large number of new oils and of the same oils after they had been used in engine runs made at the Navy Yard. This work led directly to a complete investigation of lubrication problems, which was carried out in cooperation with the Bureau of Aircraft Production. A program was decided upon covering the entire complex situation, and a laboratory fitted up especially for the purpose. Tests in actual engines under service conditions were made in the altitude laboratory, with the object of securing data upon which to base satisfactory specifications for airplane engine oils.

Miscellaneous Investigations

In addition to the investigations already mentioned, a number of others of fundamental importance have been carried out. Among these may be mentioned experiments to determine the rate of flame propagation in the cylinder of an internal-combustion engine. For this work a special single-cylinder gasoline engine has been built the cylinder and valves of which are identical with those used on the Liberty aircraft engine. Very successful preliminary results have been obtained by an electrical method developed through the cooperation of the aeronautic-power-plants section and the electrical division.

The determination of the pressure cycle in the cylinders of high-speed aircraft engines is an extremely difficult matter; in fact, until recently no successful indicator for this purpose was on the market. Indicators entirely suitable for slow-moving stationary gas engines are not at all successful in indicating the pressure ranges on light high-speed aircraft engines, due to the inertia of the indicator's moving parts. The Bureau has been working on this problem for some time, and a successful indicator has been developed which is now being manufactured on a commerical scale. The designing and constructing of a satisfactory indicator for high-speed gasoline engines will greatly aid the work of engineers in problems connected with aircraft power plants.

For many years the effect of small amounts of water injected into the intake manifold of gasoline engines has been discussed, some engineers maintaining that this practice results in the development of increased power and the removal of a large proportion

of the carbon from the cylinder and the piston. In order to investigate the merits of these claims, the Bureau conducted a set of tests in which water in varying amounts was used. The results of these experiments have been made public through one of the reports of the National Advisory Committee for Aeronautics. Many special designs of engines and accessories were submitted for test to the aeronautic-power-plants section during the war. Among these may be mentioned a small direct-injection Marburg heavy-fuel engine, a "barrel type" of engine, and a special Ford automobile engine having 16 instead of the usual 8 valves, as well as two direct-connected gasoline engines and generators designed for battery charging work for the Signal Corps. Among the gas-engine appurtenances may be mentioned the testing of a very successful mercury-cooled exhaust valve for airplane engines and the investigation of numerous carbureters with special devices for altitude compensation.

The materials-testing laboratory of the Bureau conducted a thorough study of a broken crank shaft from a small-sized Liberty engine. Tensile, hardness, impact, photomicrographic, and chemical examinations were made on this specimen. The tensile test covered those portions of the shaft forming the crank pin and cheek near the break. The only one of these various lines of study which showed any defect in the crank shaft was that for impact resistance. The Izod impact results showed an average of 50 foot-pounds of energy absorbed, while chrome-vanadium steel corresponding approximately to the analysis of this shaft usually tests about 72 foot-pounds. This lack of resistance to shock might have been due to faulty heat treatment, especially in the final drawing temperature, and those concerned with the construction and use of these engines were cautioned in that regard

AIRCRAFT CONSTRUCTION

Metal Construction for Airplanes

The tremendous increase in the use of airplanes brought about by the war resulted in an unusually heavy demand for spruce, the wood considered most suitable for constructing such machines. Even before this country entered the war in 1917, however, spruce of the required grade was becoming scarce, and this, together with the desirability of rendering the airplane noninflammable, directed the attention of engineers to the possibility of using metal for at least a portion of the airplane. Wood has some

advantages over metal, particularly where but a few machines are to be built, as the initial cost of the plant necessary for turning out the planes is much lower than for any designed to construct metal parts. Nevertheless, when the last-mentioned plant is once completed and equipped with suitable dies, tools, jigs, etc., the cost per plane is comparatively low. Therefore, metal construction appeared to offer numerous advantages where airplanes were to be produced in large quantities for military purposes.

The Bureau made a very careful study of the possibility of substituting metal for spruce for certain parts of airplanes, and undertook complete computations of the probable strength of various types of metal beams suggested for this class of construction. Many of the proposed sections were found to be impracticable and were, therefore, discarded. One type of box beam was worked out which appeared to possess the desired strength, and test beams of this design were made from sheet aluminum, and when subjected to transverse loading showed a strength well above that of Sitka spruce of standard design and equal weight.

About this time several commercial organizations engaged in fabricating sheet metal became interested in the possibility of producing a satisfactory all-metal airplane. The above-mentioned company actually constructed a complete machine similar to the Curtiss JN-4, except that it had no engine or wing covering. This was tested by the Bureau, but the wing under sand load was shown to have a factor of safety of only 2 as compared with 7 or 8 for standard wood construction. Since this result was considered unsatisfactory, a member of the Bureau's staff went to the factory of this company and aided them in producing a better design of all-metal plane. A representative of the Aircraft Board was also assigned to this work to assist in securing material, and the results accomplished were largely due to his skill and energy.

Many attempts showed that sheet metal having the necessary tensile strength could not be obtained in the nonheat-treated form, either in a carbon or chrome-vanadium alloy steel. Efforts to secure added strength by cold-rolling also failed, and for this reason the use of steel for airplane beams was given up and attention devoted to aluminum alloy. As these aluminum-alloy beams made a good showing in average strength, two complete sets of wings using this type of beam and steel ribs were constructed

by the manufacturer and tested on an airplane at McCook Field, Dayton, Ohio. During the tests, which covered about 58 hours of flying, this plane behaved in all respects in as satisfactory a manner as those made of wood. Sand-loaded tests of one of these sets of wings showed that this method of building was in every way as strong as the best wood construction. The possibility of the successful manufacture of airplanes with metal-wing frames was thus demonstrated, and the problem of insuring fireproofness of the plane now hinges on the discovery of a satisfactory noninflammable wing covering to replace the fabric ordinarily used. Although hostilities ceased before the solution of this problem was reached, considerable progress had been made and the investigation is being continued with fair prospects of success. It is hoped to develop a covering which will be not only fireproof, but transparent as well.

Many other tests of metal parts besides wing structures were conducted in this laboratory, such as hydrostatic, tensile, and compression tests of electric arc-welded longitudinal joints in steel pipes, and routine physical tests of inventors' models of ribs, beams, struts, cables, turnbuckles, etc. An investigation was carried out on triangular girders for dirigibles, and as a result it was shown that those first constructed were relatively too strong in the diagonal lattice elements and too weak in the longitudinal members. A redistribution of metal made as a result of this discovery resulted in a very satisfactory form of girder manufactured either from the French aluminum alloy "Duralumin" or its American equivalent 17-S.

Design of Variable-Camber Airplane Wing

The problem of increasing the speed range of airplanes is one of the most important in military aeronautics. The maximum speed has greatly increased within recent years and doubtless will continue to do so; but with this increase in maximum speed has come an equal increase in landing speed, since the latter has been and still remains about one-half that of the former.

Various devices may be used to increase the speed range. Among these the most promising from all points of view, including that of construction, appears to be the variable-camber wing. Such a wing, designed by a former member of the Royal Flying Corps, was thoroughly investigated by this Bureau. This wing is so constructed that at low speeds it assumes a deeply cambered or lifting form, while at high speeds it takes a stream-

line shape. In combination with wings of the usual construction in triplanes or biplanes, it allows a vastly greater speed range. The design of the wing hinges on the construction of a satisfactory variable-camber rib. This was accomplished in the wing constructed at the Bureau, and wind-tunnel tests proved it to be thoroughly practical.

Laminated Wooden Members for Airplane Construction

As mentioned in the opening paragraph of this article, the tremendous demand for airplanes during the war resulted in a scarcity of airplane spruce. Numerous attempts were made to meet this condition. One of these, that of constructing metal planes, has already been mentioned. Other possibilities were: (1) The use of some form of laminated members which would allow the utilization of spruce with less waste than in the customary construction, and (2) the discovery of suitable substitutes for spruce.

The Bureau early undertook an investigation of the first-mentioned solution and has tested many different forms of laminated construction as used in ribs, beams, struts, spars, tailbooms, and girders, and has also assisted in the development of wood veneer for wing and fuselage coverings. As a result of this work, it has been proved that laminated beams made up in a proper way are just as satisfactory as solid beams, and although the cost of manufacturing is somewhat greater, the reduced cost of the raw material utilized results in a saving. Cross-sections of some of the laminated wooden beams which the Bureau tested are given in Fig. 6. In addition to the tests conducted on solid and laminated beams of the same kind of wood, this series furnished comparative data on the strengths of such woods as spruce, fir, and cypress, and the relative advantages of rectangular and oblique I-sections, and on the strengths of various types of joints and different brands of glues.

It was shown that beams of fir can be produced which will have as high a specific strength as those made from spruce, although such beams will not be quite so stiff. Cypress can not be considered as a satisfactory wood for this construction. Beams made up of pieces glued together were proved to be as strong in shear as the solid wood, and no weakening of the bond with glued joints was observed even when subjected to moisture and vibration.

In addition to the test on beams, research work was conducted on many other wood members. An interesting test was that of

an experimental three-ply mahogany veneer-covered wing. This wing was constructed with glued joints throughout, no nails or screws being used. Two different designs of rib were submitted with the wing, one of which proved to be considerably superior to the other. When subjected to drifting and sand-load tests, the wing showed a satisfactory strength; but since its weight was approximately 30 per cent in excess of the ordinary type of fabric-covered wing, it could not be considered altogether satisfactory. Other miscellaneous tests included those on so-called "pigeon hollow" spars, Navy model—T-spars, etc.

In the investigation and development of various types of airplane struts, the value of the Bureau's work is very forcibly shown. Tests of veneer struts were under way on the day America declared war upon Germany. Many different styles were investigated and certain types of veneer construction were shown to be satisfactory. The compressive strength of such members was investigated. Many types of square-end and round-end struts of various slenderness ratios were tested, and as a consequence of this work rational mathematical expressions were formulated and constants evaluated which give results corresponding closely to the values determined experimentally. Prof. Boyd likewise developed a formula of more general application, which is suitable for use in connection with the tapered struts used in airplane wing construction.

Various Wood Species as Spruce Substitutes

As another possible means of assisting in the rapid production of military airplanes, the Bureau, in cooperation with the Aircraft Production Board, undertook an investigation of the possibility of using woods other than spruce. The investigation of the different types of woods was one of the most complete carried out by this laboratory. Woods of all promising species were investigated, and many special tests were developed for use in this connection, some of which required the use of novel designs of testing apparatus. A special hammer for a beam-impact testing machine and a rotating bar machine for fatigue testing were designed particularly for this investigation. On the basis of these tests, a table and data were furnished showing the relative values of various woods for airplane work.

Artificial Drying Processes for Wood

The successful substitution of other species of wood for spruce in airplane construction depended very largely upon the discovery

of a satisfactory quick-drying process which would not check the woods. Air drying is, of course, the ideal method for preparing lumber for the mill, but in the case of certain species of wood it involves months or even years of delay. The Bureau's participation in the development of suitable artificial drying processes consisted chiefly in the inspection of the plants of operators using various patented processes, in proposing desirable improvements, and in testing the products. In nearly all of the plants inspected it was found that no particular engineering skill had been used in the kiln or plant construction, and the operators did not appear to have much knowledge of wood technology. The Bureau's suggestions were thankfully received and promptly put into operation in the majority of instances with marked gains in plant efficiency. Some of the processes investigated indicated that it was possible to produce wood equal in strength to that dried in air by artificial drying methods with a great saving in time.

Wood Protective Coatings

For certain parts of the airplane structure, such as the propeller, the protection of a metal coating or a composition impregnation has proved highly desirable. Initial tests on electrodeposited sheet copper for such a purpose led to the conclusion that a satisfactory grade of this material could be produced. The covering of the entire propeller involved too great an increase in weight, however, to be practical, but the plating of the tip of the blades has been successfully carried out. Bakelite-impregnated woods were also investigated with the idea of using them for propeller construction and also for the manufacture of motor-truck steering wheels. Bakelite-impregnated maple and walnut specimens showed increased strength over ordinary wood, but the weight increases were so great that such wood was not deemed suitable for aircraft use, although it has been successfully employed in automobile work.

AIRCRAFT MATERIALS

Airplane Dopes

A complete description of the Bureau's work in this field will be found in the article under the above heading.

Paper as a Substitute for Linen in Airplane Construction

This work is described in the article on "Paper."

Development of Satisfactory Cotton Fabric for Airplane Wings

This work is treated under the heading "Textiles."

Balloon Fabrics

Radiant-power life tests of quartz-mercury vapor lamps: This work was undertaken in connection with the investigation of the deterioration of balloon fabrics when exposed to sunlight and ultra-violet light.

The ultra-violet as distinguished from the infra-red rays appear to have a marked effect in accelerating chemical action; as, for example, in the fading of dyes. There has arisen among manufacturers of paper, dyes, cloth, rubber goods, paints, etc., a need for information concerning the sources and their constancy of emission of ultra-violet radiations, for use in testing the lasting quality of their products.

It is well known that the intensity of the radiation (especially the ultra-violet component) from quartz-mercury vapor lamps, decreases greatly with usage.

In response to the demand for exact data, methods were devised for determining quantitatively the decrease in intensity of emission with usage, and measurements were made on radiant-power life tests of a number of quartz-mercury vapor lamps, using the radiometric instruments devised at this Bureau, and described in Scientific Papers Nos. 229 and 282.

The data obtained indicate a marked decrease in the total radiation emitted, as well as the ultra-violet component, in the course of 1000 hours' usage of the quartz-mercury vapor lamps now obtainable on the market. See Scientific Papers Nos. 196 and 244.

In connection with the general investigation (chemical, mechanical, etc.) of this subject, the transmissive and reflective properties of numerous samples of balloon fabrics were determined, using a hemispherical mirror and thermopile. Measurements were made also of the rise in temperature when the fabrics were exposed to solar radiation, using a modification of the fine thermocouples used in measuring heat from stars.

Investigation of the Thermal Expansion of Materials Used in Aircraft-Engine Construction

The thermal expansion of the materials used in the building of aircraft engines was determined by the Bureau, to aid in the selection of proper metals and alloys for the various parts.

AIRCRAFT (MISCELLANEOUS)

Instruments for Measuring Tautness of Airplane Wires and Cables

In an attempt to reduce the weight of airplanes to an absolute minimum the factors of safety employed in the design of many

of the members were frequently lowered during the war. Since in many cases the stresses set up in the members by the initial tension in the stay wires is a large percentage of the total stress to which they are subjected, it therefore becomes important to know the magnitude of these loads. No satisfactory instruments were available to manufacturers or inspectors in the early stages of the war for determining the initial load on the stay wires. A "tuning" method was used in some instances with satisfactory results, but this method required an observer with a highly trained musical ear.

The Bureau attempted the solution of this problem, which was successfully completed by a member of the Bureau's staff. An instrument known as a tensiometer was designed and built in the latter part of 1917. (See Fig. 7.) The instrument is now being successfully used by both the Army and Navy in their airplane-manufacturing plants. It requires no special skill or experience in its operation and has been found to give results sufficiently accurate for all practical purposes.

The design is simple and is based on the fundamental principles of mechanics. If any balanced system of forces acts at a point, the resultant force is equal to zero by definition. If a wire is supported at two points and deflected at the middle of the span thus formed, we have a system of forces in equilibrium. Knowing the length of span, the amount of deflection at the center, and the force required to produce this deflection, it is possible to calculate the tension in the wire.

The tensiometer provides a convenient method of obtaining the necessary data for this solution. The wire is supported on two pins at a known distance apart and loaded at the center of the span thus formed. Load is applied through a yoke, spring, and plunger by the closing of hand levers. The required deflection of the wire is indicated by an Ames dial and the corresponding lateral forces exerted on the wire are shown by another dial. We know that the tension in the wire is proportional to the load on the spring for a given amount of deflection and it is therefore possible to make the second dial indicate the tension directly by always deflecting the wire a constant distance. The design of the instrument is such that estimated divisions on the second dial indicate pounds of tension on the wire for the standard deflection of one-tenth inch (or one revolution of the first dial).

The instrument is portable, quick reading, and does not have to be attached integrally to the wire at any time. The instrument

can be constructed so as to give direct load readings for the type of wire most commonly encountered in the construction of the planes on which it is designed to be used. For shapes and sizes of wires differing materially from those for which the instrument was designed, it is necessary to apply correction factors. Instruments have been built for use on cables of various sizes and on wires of circular and stream-line shapes.

The Bureau was subsequently called on to conduct calibrations of other types of instruments designed for this purpose, but these were found to be more dependent than the tensiometer on the skill of manipulation and the position in which the instrument was applied. They also suffered from unsatisfactory mechanical construction and in some cases were based on incorrect principles. Most of them used varying deflections of the wire for different tensions on the wire. This prevented the instruments from being self-indicating, and calibration curves or tables always had to be used to enable the observer to determine the tension.

Synchronizing Devices for Airplane Guns

Tests were made upon a hydraulic synchronizing system such as is used in synchronizing machine-gun fire from airplanes. These tests were made in order to determine the effect of varying the size of different parts on the operation of the mechanism.

The operation of the gear may be described as follows: The necessary pressure in the system is effected by means of oil in a high-pressure plunger tube and is maintained by a reservoir plunger spring. A needle valve operated from the airplane control stock closes the opening to a low-pressure tube and at the same time opens a ball valve, which in turn releases the pressure to the auxiliary pipe lines. This pressure forces a hardened steel ball attached to the end of a generator plunger against a cam which is mounted on a rotating axle. When the cam is rotated so as to move the plunger, the oil in the system is forced through two pipe lines—an auxiliary and a main—against the plunger in the reservoir, and against the base of the trigger motor.

The pressure per unit area exerted by the reservoir plunger is not sufficient to produce motion of the trigger-motor plunger. Hence, if the cam is rotated slowly enough to allow the oil to flow through the auxiliary pipe line, the trigger motor will not operate. However, as the tube connecting the generator and reservoir is very small, the viscous forces are so large that considerable resistance is offered to the rapid movement of liquid through this tube.

FIG. 7.—*Tensiometer for measuring the tension of airplane wires*

There is a correct tension for every wire used in the "standing rigging" of an airplane. The tension on a wire is shown in a few seconds by this instrument

FIG. 8.—*Two views of the Dover By-Product Coke Co.'s plant at Canal Dover, Ohio*

The bureau, in cooperation with the Bureau of Mines, carried on extensive tests on the coking of low-grade midcontinent coal in the Roberts ovens installed at this plant

Hence, when the cam is rotated rapidly, the resistance in the auxiliary pipe due to viscosity is so great that the liquid is forced through the main pipe against the base of the trigger motor with sufficient force to operate the plunger of the trigger motor.

The minimum speed at which the trigger motor will function will depend not only on the relative sizes and lengths of the two pipe lines, but also upon the strength of the plunger spring and the trigger-motor spring. When the speed is sufficiently high to make the operation satisfactory, there is comparatively little motion of oil in the auxiliary pipe line. Attention may then be concentrated on the main pipe line. The movement of the generator plunger during the rotation of the cam causes an increase of pressure in the main pipe line. This pressure is not immediately communicated to the trigger-motor end of the pipe line, but passes down as a pressure wave.

The three factors which affect to some extent the velocity with which this wave is propagated are:

1. The expansion of the copper tube of the main pipe line under the increased pressure. Since the copper walls are thick (one-eighth inch), this expansion relative to the compression of the oil is small and may be neglected.

2. The compression of the oil in the main pipe line due to its retardation by viscous forces which are developed when a liquid is forced at a rapid rate through a small tube. Computations of the pressure thus developed at the generator plunger by a speed of 1200 rpm show that the pressure at this end of the main pipe line for a 6-inch pipe is not in excess of 10 pounds per square inch over that of the motor end.

3. The compression of the liquid due to its inertia. Computations of the pressure due to the inertia of the liquid show that at the same speed the pressure at the generator end of the main pipe line exceeds that of the motor end by 4000 pounds per square inch for a 6-foot pipe, and 6600 pounds per square inch for a 10-foot pipe.

The inertia effect may then be considered as the important factor in preventing the instantaneous equalization of pressure in the main pipe line. This pressure wave is propagated in the same manner as a sound wave; therefore at approximately the same velocity. This velocity determines the time lag between the generator and the motor, but has no relation to the velocity of the liquid in the pipe.

The effect of changing the various elements of the system is as follows:

1. Increasing the strength of the spring in the reservoir increases the pressure in the system, and, therefore, puts a greater initial pressure on the spring of the trigger motor. It also has the advantage of compressing any small air bubble.

2. Changing the size and length of the auxiliary pipe line. Decreasing the size and increasing the length increases the resistance offered to the flow of the liquid, hence the slower the speed at which the apparatus will operate. If the auxiliary pipe line becomes too short, the oil system may have very little damping, so that chattering of the plunger of the trigger motor may occur

3. Size of the main pipe line. Increasing the main pipe lines does not materially affect the rate of propagation of the wave; but, since it increases the mass of the liquid, the strength of the trigger-motor spring must be increased in order that the plunger of the generator may at all times be in contact with the cam.

4. Length of the main pipe line. Increasing the length of the main pipe line increases the time for transmission of the pressure wave and also increases the mass of the liquid. In case the pipe is too short, chattering of the trigger-motor plunger occurs, due to the very small amount of damping. In the results obtained some chattering has occurred in most cases. This, however, is not excessive, and it is not believed to be sufficient to be the cause of stray shots, since the extrusions are too small to cause firing of the gun.

From the discussion above it will be seen that the factors enumerated will determine a suitable design for a given installation.

The experiments performed from which the above results were obtained are described below. Two methods of measurement were used—the rotating drum method and the stroboscopic method.

In the rotating-drum method the movements of the plunger of the trigger motor were recorded on a rotating drum operated by the same motor as the generator cam. A stylus attached to the trigger motor recorded its movements on a paper carried by the rotating drum.

In the stroboscopic method two disks were used, one being mounted on the end of the motor shaft and the other near the first on a shaft coaxial with the motor shaft, which was rotated by

hand. On the latter disk was a scale graduated in degrees and read by means of a stationary pointer. To make an observation the position of the pointer was read when the highest part of the cam was pressing against the ball of the generator plunger. The motor was started, the speed of the motor determined, and the fixed disk rotated until the trigger-motor plunger was at its maximum extrusion, when the position of the pointer was again read. The time required for the rotating disk to turn through the observed angle of rotation of the fixed disk is the time for the transmission of the pressure wave from the generator plunger to the trigger-motor plunger and for the trigger-motor plunger to act.

Measurements taken in this manner give values for the time lag of from 0.002 to 0.004 second. The observations taken were insufficient to determine accurately the velocity of propagation. However, values ranging from 1500 to 4000 feet per second were obtained.

The effects of removing the damping valve from the T-piece upon chattering of the trigger motor were also observed. The experiments were made with the Constantinesco system set up in the regular manner. This is the hydraulic system in most general use and was used in making the preceding tests. It was found that when strong springs were used in both the trigger motor and reservoir a little more chattering occurred with the damping valve removed.

In order to determine the effect of using different lengths of pipe line, tests were made with lengths of 10, 6, 4½, and 1½ feet. For all lengths of 4½ feet or more, no differences were noted in the trigger-motor plunger. This was the case for various pressures in the reservoir, various speeds of the generator, and for the removal of the damping valve. For short lengths of pipe, the system was found to operate better under low pressures, the extrusions of the trigger-motor plunger being exceedingly large for high pressures.

With the reservoir plunger spring removed tests were made upon the pressure required to operate the system. This depends upon the strength of the trigger-motor spring and is independent of the length of pipe line. With a 25-pound trigger-motor spring, 70 to 90 pounds pressure was necessary to operate the system, increasing for a 50-pound spring to 100 to 125 pounds.

The effect upon the trigger-motor action of varying the speed was also studied. It was found that the initial parts of the impulses were very much alike, also that they occurred at approxi-

mately the same place on the drum. However, at 1200 rpm the plunger remained at its maximum extrusion for a longer time. This is caused by the fact that the trigger-motor plunger is returned by the force of the spring.

Some general observations were made upon the working of the system as to the number of bursts, effect of air, and kinks in the system. With the Constantinesco system of gears, the average of several trials was 24 bursts. No direct effect could be noted as a result of kinking the pipe. However, kinks in the pipe make it hard to free the sytem from air. The washers used during the tests were of English composition and were found to be very satisfactory. Both English and American made reservoirs were used. The valve fittings on the English reservoir gave less leakage trouble. An English generator was used in making the tests. It worked very satisfactorily and showed no signs of wear.

In order to determine something of the behavior of the oil when the system was being operated, the top half of the pipe line was cut away for a distance of about 3 inches, and a piece of glass was slipped over the hole. The motion of a rider placed on a fine copper wire stretched along the slit was then observed. The observations showed that in the transmission of the generator-plunger action to the trigger motor, there was a movement of the oil as well as a compression wave.

The oil used in the system during the experiments consisted of about 9 parts kerosene and 1 part machine oil. A test was also made as to the effect of using Liberty-motor oil in the system. No difference could be noted in the operation when this oil was used.

A great number of tests were made with the Marlin trigger motor. For an indicator a small brass strip was soldered directly to the trigger-motor plunger. For pressure tests, variation of speed, and lengths of pipe line, the same results were obtained as with the Constantinesco system. However, the construction of the trigger motor permitted a greater motion of the trigger-motor plunger, and for rather great pressures, very great extrusions of the trigger motor were obtained. The tests made with the system are not, however, conclusive, due to the fact that the complete Marlin system was not operated together. The generator used belonged to the Constantinesco system. The difference in this generator from the Marlin, quite likely, would influence the results.

On June 17, 1918, an officer who had had extensive experience in flying on the European battlefields visited the Bureau and pointed out the need of a synchronizing gear or gun-control system, which would permit of the gun being fired through the propeller in any direction at the will of the operator. He was of the opinion that an electrical type of gear would most easily meet the requirements imposed by the movable-gun feature. On July 24 a communication from the office of the director of military aeronautics requested that the work on this electrical synchronizing gear be carried to completion.

After several conferences and some preliminary work the problem was taken up actively about the middle of August, 1917. At that time, a modification had been made in one of the heavy Browning guns under the direction of two officers of the Ordnance Department. The modification replaced the regular sear and trigger by a sear operated from above and back of the bolt by a link which moved in a direction parallel with the barrel of the gun. The purpose of this modification was to get a more direct action between the sear and an electromagnet or solenoid with which it was proposed to fire the gun.

If the gun is to be fired through the propeller in any direction at will, the phase of the control mechanism must be changed as the position of the gun is changed, otherwise adjustments which are correct for one position of the gun would not be correct for other positions, and the propeller blades be struck by projectiles. As the position of the gun is changed, the control apparatus should change the phase of firing by the same amount that the line of fire is changed with respect to the axis of the propeller.

With most synchronizing systems, adjustments are made so that the gun fires only a safe distance back of the propeller blades with the propeller at rest, or turning with a fairly low speed; then as the speed is increased the gun fires further and further back of the blades, and at the highest permissible speeds may be firing just ahead of the next blade. With a propeller speed of 1800 rpm the blades rotate through an angle of about 11° in 0.001 second and with the two-blade propeller the safety zone between blades may be considered to be about 145°. Consequently, if the gun is to be fired at any speed from 0 to 1800 rpm it is necessary either to advance the phase of the control mechanism as the speed increases or make the over-all time lag less than 0.013 second. Any arrangement which would automatically change the phase of firing with

changes in speed would add to the complication of the apparatus, and thus should be avoided if possible. We may, therefore, consider that we must keep the over-all time lag less than 0.013 second.

The over-all time lag depends upon the time required for the separate operations which must occur in succession between the beginning of the actuation of the control mechanism and the passage of the projectile through the plane of the propeller. It includes the time required for the action of the control motor (the timing apparatus connected directly or indirectly to the propeller or crank shaft), the time required for this action to be transferred to the trigger motor (the apparatus which actuates the trigger, or sear, and releases the firing mechanism of the gun); the operation of the trigger motor and sear; the operation of the firing mechanism or firing pin of the gun, and the explosion of the charge and the passage of the projectile through the barrel of the gun and through the plane to the propeller. The time required for the last-mentioned operations depends upon the ammunition and position of the gun on the plane. With the regular ammunition and the gun at a distance of 6 feet from the propeller, it amounts to about 0.0035 second. It can not be made much less than this, since usually the gun can not conveniently be placed much closer to the propeller, and it is not practicable to obtain quicker action ammunition. The time required for operation of the firing pin of the Browning heavy field gun is about 0.006 second. With this gun set at a distance of 6 feet from the plane of the propeller, we would have only 0.004 second as the maximum possible time for the action of the entire control system, unless the phase of the control apparatus were to be advanced as the speed of the propeller is increased. With the Browning aircraft gun, the time required for the operation of the firing pin is probably about 0.0015 second; consequently the permissible time for the operation of the control system is about 0.009 second.

A preliminary study of the problem showed that it would not be practicable to fire the heavy Browning gun as modified with any type of solenoid or electromagnet. The difficulty with apparatus of this type is that it would be entirely too slow in action to meet the conditions of the problem, since the inertia of the sear and sear trigger together with that of the armature or plunger would necessarily be large, and the force which could be produced would be small. This preliminary study showed further that if an electrical control system were to be considered,

it should preferably be one in which the work of accelerating the sear and the other moving parts of the control system would be furnished by the recoil of the gun rather than by any type of electric motor which for each shot would have to start from rest and perform its function within a few thousandths of a second. Later a suggestion was made by Maj. Martel that the recoil of the gun might be used to set an actuating lever and spring which, by means of an electromagnet, would be tripped when it was desired to fire the gun.

The plan adopted for the control gear was to have the recoil of some part of the gun move the armature, against the action of a stiff spring, adjacent to the pole pieces of an energized electromagnet. Then when it is desired to fire the gun, it is necessary only to break the circuit of the electromagnet or otherwise suddenly cause a material reduction in the current. This releases the armature from the pole pieces and it moves quickly under the action of the stiff spring into contact with and releases the firing mechanism of the gun. As actually carried out, the armature is released in about 0.001 second after the propeller reaches the desired position for firing, and the armature moves the distance required for firing the gun in about 0.002 second more. Thus the entire control mechanism performs its functions in about 0.003 second.

With the first apparatus constructed, the target was made with a burst of 100 shots with a fixed gun, when the propeller was running at the rate of 850 rpm, and two shots when the propeller was being turned very slowly by hand. Measurements made from this target showed that the over-all time lag, including the action of the control mechanism, the action of the firing pin, the action of the primer and the charge, and the passage of the projectile to about 4 feet beyond the muzzle of the gun was slightly less than 0.01 second, and the variation of this time for different shots was slightly less than 0.001 second.

With the second control apparatus the results obtained were not so good. However, the causes for the inferior action were definitely located and found to be of a kind which could easily and certainly be remedied by changes in the proportions of the parts.

Recovery of Helium from Natural Gas

Paragraphs briefly describing this work will be found under heading "Natural Gas Investigation."

AIRPLANE DOPES

Introduction

The chemistry division of the Bureau of Standards became interested in the treatment of airplane wings during the six months preceding a declaration of war by this country. At that time the value of air strategy in military operations had been fully demonstrated abroad, and the attention of the War Department was directed to the development of heavier-than-air craft in this country. The Signal Corps was directed to design and build types of aircraft suitable for the purpose. The first planes constructed were doped with nitrate dope prepared from cellulose nitrate or guncotton. Acetate dopes prepared from cellulose acetate had been used in this country, and the cellulose acetate manufactured by the Bayer Co. of Germany and known as "Cellit" was employed. Supplies of the material in this country were rapidly exhausted, and for a time the nitrate dope only was available. One of the large makers of photographic supplies, in the manufacture of a noninflammable moving-picture film, had accumulated considerable quantities of cuttings and scraps of the film consisting essentially of cellulose acetate. Subsequently this material was used in the preparation of acetate dope for a considerable time. It contained in addition to cellulose acetate residues of plastic, including compounds, and as a rule the material had aged considerably.

In the preparation of dopes additional amounts of plastics were added, the material was frequently overloaded with these compounds, and the durability of such dopes was not as satisfactory as that of products prepared directly from cellulose acetate. The amount of raw material available for dopes of this type was limited.

In the construction of airplanes the question of a suitable dope properly applied is usually considered of no importance and receives scant attention. This was the experience of England and later of America until the necessity of stripping the fabric from a plane improperly doped, re-covering, and redoping it was found to involve considerable expense. The airplane program as originally planned overlooked the subject of dopes entirely in spite of protests from the War Industries Board and this Bureau. Owing to the sudden expansion of the Signal Corps, difficulties of organization, and the greater importance of other problems this fact is not surprising. Not until seven months after the declaration of war was provision made for insuring an adequate supply

of raw material. When action was finally taken, the total supply of raw material necessary for the preparation of solvents and cellulose acetate was commandeered by the Government.

Until the War Department was able to provide a personnel for the consideration of doping problems all questions on the subject were referred to this Bureau. Samples of dopes submitted by lacquer and varnish companies were examined to determine their value in the construction of aircraft. Material of suitable quality was assigned to a "list of approved dopes." In cooperation with the Society of Automotive Engineers the Bureau assembled a committee to prepare specifications. Representatives of the Government, dope manufacturers, and constructors of aircraft met on several occasions and suitable specifications were submitted and accepted by the War and Navy Departments. A decision was also rendered by the committee in regard to acetate dopes containing tetrachlorethane as solvent. This compound has marked toxic properties and may be decomposed with the liberation of hydrochloric acid. The committee on dopes decided that the use of this solvent involved considerable danger to workmen and that no dopes containing it were to be used on Government aircraft.

A representative of this Bureau conferred with Signal Corps officials on numerous occasions before a section and laboratory were organized by the War Department. Questions relating to raw materials, cellulose acetate, solvents, plastics, the relative merits of dopes on the approved list, and the preparation of standard formulas for acetate and nitrate dopes received consideration. Assistance was also rendered in the preparation of reports on various topics. Subsequently work was carried out on the pigmentation of dopes for the Department of Military Aeronautics and a report submitted on this subject.

The Navy Department consistently conferred with this Bureau throughout the period of hostilities, and the Bureau represented the Navy Department in several conferences with representatives of the War Department. In cooperation with the Bureau of Construction and Repair, specifications were prepared for the compounds entering into the standard dopes, and for solvents intended for repair work. Work was carried out on fireproofed dopes, solutions proposed as dope substitutes, and on the fireproofing of silk-balloon flares. Several trips were taken to aircraft factories for the solution of problems connected with the practical application of dope, control of humidity, and the relation of dope to fabrics.

Function and History of Dopes

A dope is applied to airplane fabric covering wings and fuselage to shrink it, making it drum tight, and to stabilize it, so that no changes occur under varying conditions of humidity and temperature. Resiliency in flight and lifting qualities are thus imparted to the plane. The dope also fills in the interstices of the fabric and makes it impermeable to wind and moisture. It should afford a smooth surface so that skin friction or surface resistance to the wind is reduced to a minimum, and it should be as resistent to fire as possible.

When heavier-than-air craft were first constructed, the wings were covered with unproofed cotton stretched as tightly as possible. Flying could be attempted only in fine weather, and the necessity of some treatment which would make the plane weatherproof was apparent. Various treatments were given a trial, but for numerous reasons rejected. The treatment was affected by weather conditions, or added too much weight to the plane, or lacked durability, or the oil from the motor penetrated the coating, which was softened and lost its original tautness.

Rubberized fabrics were tried, and fabrics were coated with compositions of glue and casein, as such, or treated with bichromate or formaldehyde to render them insoluble. Mixtures of paraffin and beeswax were used, linseed oil, shellac, and varnishes. A French art student, Voisin, who later became an aviator, recalled the use of starch paste to tighten a canvas before painting. This was tried on an airplane wing and found suitable, but it lacked durability. The value of shrinkage, however, was demonstrated. Starch paste is used to-day in experimental work.

Subsequently, solutions of collodion or guncotton were found to produce excellent shrinkage. Because of the inflammability of guncotton, the use of thin sheets of cellulose acetate was recommended, and this led to the use of cellulose acetate in solution. These solutions were exploited chiefly by Eichengrün, a German chemist. Cellulose-acetate dopes are now in common use, particularly on planes designed for combat purposes. The cellulose esters belong to the class of colloidal compounds, and shrinkage is a characteristic property of such compounds when drying from a solution.

Dopes are also used on balloon fabric to reduce the permeability of the fabric to gas. The English Government uses Delta dope for this purpose, a nitrate dope containing sufficient castor oil to

make it nonshrinking. The Navy Department has used Delta dope on certain airships, on which the fabric had become too permeable to gas, and satisfactory results were obtained. Acetate dopes may also be used for this purpose.

Composition of Dopes

A dope consists of the cellulose ester dissolved in suitable solvents to which diluents are added, with the addition of plastics and a compound to neutralize the traces of acidity in the solvents or acidity which may develop in the film. The solvent contains a compound of high-boiling point which allows the cellulose ester to emerge from the solvent mixture in a transparent condition, free from precipitated cellulose ester which would appear in the film in streaks or spots. The development of such whitened areas is known as "blushing." It results from the application of dope in a humid atmosphere, or from the rapid evaporation of low-boiling solvents and diluents, or both. In the presence of a high-boiling solvent, the moisture has a chance to evaporate before the film is dry, and the cellulose ester is not precipitated. The amount of the "high boiler," as it is frequently called, depends upon its boiling point. If the latter is high, less of the compound is needed than when it is low. Solvents with boiling points between 125° and 200° C are generally used. A high-boiling diluent may be present in nitrate dopes to assist in the prevention of blushing.

Diluents generally consist of mixtures of alcohols and hydrocarbons, and frequently denatured ethyl alcohol and benzene are used.

Plastics are occasionally used in nitrate dopes, but are always present in acetate dopes. The nitrate film has sufficient inherent strength and elasticity, without further modification, but a small amount of castor oil or camphor is sometimes incorporated in it. Cellulose acetate, however, is inherently brittle, and certain softening bodies or plastics must be added to it in order to impart suppleness and increase its life. A plastic is frequently a solid of low melting point, sometimes a liquid or a mixture of liquids, and generally a solvent of the cellulose ester, with which it forms a solid solution. A small amount of the "high boiler" is always left in the dope film, and this also plasticizes it. A suitable base is generally present in the film to neutralize acidity. The base commonly used is urea.

Cellulose Nitrate Dopes

Cellulose nitrate or guncotton is produced by the nitration of cotton or some form of cellulose approximating the degree of purity of cotton. For dopes a low-nitrated cotton is desirable. It must be stable in order that no decomposition with development of acidity may occur. The high boiler in nitrate dopes is generally amyl acetate or butyl acetate. The former is a product of fusel oil, and the latter is prepared from butyl alcohol, a by-product in the production of acetone by fermentation. The diluent is generally a mixture of denatured alcohol and benzene, although methyl alcohol, methyl acetone, and xylene are also employed. A low-boiling solvent, such as ethyl acetate, may also be present. The solvent and diluent combination used in nitrate dopes is influenced by the degree and method of nitration, and, therefore, is subject to considerable variation.

Cellulose-Acetate Dopes

The manufacture of cellulose acetate is a technical art, demanding careful supervision and control. Variations of a few degrees of temperature during the process have an adverse effect upon the product. The correct preparation of the material is known to but a few chemists. It is quite difficult to make two batches of the ester alike, and frequently there is trouble in spite of efforts to keep the quality uniform. The material is a white solid, its appearance depending upon the method employed for its precipitation. A good cellulose acetate has an asbestoslike quality when rubbed between the fingers.

The commonest "high boiler" used in this country in acetate dopes is diacetone alcohol, a product of acetone obtained by condensation in the presence of lime. In Germany, before the war, ethyl lactate was the "high boiler" in common use. This substance has a tendency to break up into ethyl alcohol and lactic acid unless certain compounds are added to it to make it stable. Methyl ethyl ketone in suitable amount also prevents blushing, but not as effectively as the preceding compounds, unless a considerable amount is present. In this connection it may be pointed out that a suitable proportion of alcohol and benzene, when present in the dope, removes much of the moisture present. A certain mixture of alcohol, benzene, and water has a higher vapor pressure than any of its constituents, and, when this mixture results during evaporation, water is readily removed. No practical application has been made of this fact. Acetone oils are

also used as high boilers, but the composition of these oils varies greatly, and because they may break up with the development of acidity unless carefully purified, they have not found as much favor as compounds of known purity.

Solvents are usually acetone, methyl acetate, methyl acetone, tetrachlorethane, and ethyl formate. Acetone was not used during the period of hostilities because it was thought to be necessary in the preparation of cordite and for other purposes. The preparation of methyl acetate involves less consumption of acetate of lime than the production of acetone, and hence has been preferred because its use conserves raw material. Methyl acetone is a product of the destructive distillation of wood. It is largely a mixture of acetone and methyl alcohol, and when the latter is acetylated, the water removed, and the acid present neutralized, a good solvent results. The composition of methyl acetone varies considerably, and sometimes it is necessary to increase its solvent power by the addition of methyl acetate or acetone. Tetrachlorethane was formerly a favorite solvent in acetate dopes. It combines the functions of a solvent and plastic and dissolves cellulose acetates of a wide degree of hydration. However, its vapor has been shown to be about four times as toxic as that of chloroform, and, unless pure, it decomposes and causes deterioration of the fabric. The vapor of the compound causes jaundice, and in England several fatalities resulted from the application of dopes containing it. The decomposition of tetrachlorethane can be prevented, and the danger attending its application could be nullified if all the doping rooms were provided with adequate means of ventilation. Unfortunately, ideal conditions of ventilation do not exist, and one by one various Governments have all abandoned the use of tetrachlorethane dopes. France and Italy have even ruled out dopes containing chlorine in any form.

Ethyl formate has not been used in the United States, but is allowed by the British Government. It is an excellent solvent.

The diluents commonly used are denatured alcohol and benzene, and sometimes methyl alcohol either added as such or present in methyl acetone. Cellulose acetate dissolves in a mixture of alcohol and hydrocarbon when warmed and is reprecipitiated in the cold, but the solubility persists in the presence of a solvent. When the ratio of hydrocarbon to alcohol is three to one, an increased amount of diluent may be used.

The plastics which have been proposed for use in acetate dopes include many compounds, some of which are much superior to

others. Benzyl alcohol is used by the British Government. Mixtures of eugenol and triacetin have found favor in France. In this country the commonest are phenyl salicylate, which is an excellent softener, mixtures of benzyl benzoate and benzyl acetate, benzyl acetate alone, and triacetin. Triacetin is soluble in water, and may decompose with the liberation of acetic acid. Triphenyl phosphate is in universal use in acetate dopes. It waterproofs and fireproofs the film, and is an excellent softener. When used in excess, however, triphenyl phosphate softens in warm weather and makes the acetate film soggy. Urea is used in small amount to neutralize any free acid which may be present.

Dope Covers

The dope, as has been previously mentioned, protects the fabric, keeping it taut so that flying is possible under all weather conditions. It is also necessary to protect the dope film by covering it with some suitable coating containing pigments to exclude light rays. Either pigmented dopes or varnish enamels are used for this purpose.

Pigmented dopes are preferable because they dry more quickly and are more suitable for quick repairs. If varnishes or enamels are used, the dope must be thoroughly dry, as residues of high-boiling compounds may dissolve some of the oil in the varnish and carry it into the dope film, and thus cause a relaxation of the fabric.

It has been conclusively proved by the Royal Aircraft Factory that the deterioration of dopes is practically entirely caused by sunlight. A prolonged investigation indicates that the curves of the intensity of sunlight and the curve of deterioration of doped fabrics are almost identical. It is, therefore, more feasible to use a pigmented dope or a pigmented wood-oil varnish than clear dope or varnish as a dope cover. Clear varnish has until recently been used in this country on Army planes, while the Navy has used a gray pigmented varnish enamel. The Royal Aircraft Factory has recently demonstrated that doped fabrics covered with pigmented dope retain their tautness longer than similar fabrics covered with an enamel. It has also been demonstrated that a pigmented dope retains its tautness best of all, and that such a dope effects a considerable saving of cellulose acetate. The English Government for a long time has used a type of pigmented dope cover, khaki colored by iron pigments and lampblack, which is called P. C. 10. It is a nitrate dope containing the above pigments and sufficient castor oil to reduce to a minimum the shrink-

age ordinarily effected by a dope. Reports from the front indicated that the use of such a cover has resulted in excellent retention of the tautness and durability over a long period.

Dope covers may be colored black by means of lampblack. A dull-black surface is produced which is suitable for flying at night. Similarly, an aluminum finish may be used on planes designed for use in hot, dry climates, because of the highly reflective surface produced. Other effects are possible by a proper choice of pigments.

Application of Dopes

In the application of dopes to fabrics, it should be remembered that the fabric does not of itself shrink in the sense that mercerization causes shrinkage. In other words, there is no physical change occurring in the fabric. The dope film contracts when drying out of solution and diminishes the space between the threads, the total effect of which is to reduce slightly the area originally covered by the fabric when under a given tension. The British Government at one time used a dilute solution of dope next to the fabric. This was called a "scratch coat." The dope contained very little softening agent, and possessed maximum contractibility. The scratch coat, however, was found to reduce the tear resistance of the fabric and was, therefore, abandoned. Such a coating penetrates the fabric very thoroughly and locks the fibers and threads. It is apparent that the viscosity of the dope must permit of some penetration, so that the dope will not peel off, but the penetration must not be excessive. The amount of size in the fabric to some extent influences penetration. The first coat of dope is well worked into the fabric, and subsequent coats are flowed over it, care being taken not to go over a given area more than once or twice, or the doping brush will drag over the dope film. Sufficient dope is applied to produce an increase of weight of 2 to 2.5 ounces per square yard. The Army specifications require four coats of dope on all planes, and specify nitrate dope on training planes and acetate dope on combat planes. Two coats of clear varnish or enamel are applied over the dope.

The Navy Department specifies two coats of acetate dope over the fabric, followed by three coats of nitrate dope and two coats of Navy gray enamel. The inflammable nitrate dope is thus laminated between the relatively fire-resistant acetate dope and enamel, the pigment of which also affords resistance to fire. It has been contended that the use of one type of dope above the other may produce two films of different physical properties, but to date no

trouble has been experienced by the Navy in the durability of dopes applied as above.

Fireproofed Dopes

Inasmuch as nitrate dope is comparatively cheap and acetate dope quite expensive, numerous attempts have been made to reduce the inflammability of the nitrate film. This has been attempted by fireproofing the fabric or dope or both. Fireproofing is generally effected in one of three ways: By incasing the material in a coating of inert mineral salts; by using compounds which decompose with the liberation of a gas which checks combustion, or by incorporating an organic fireproofing compound in the dope film.

Any compound used for checking the spread of combustion should not hydrolyze with an acid or alkaline reaction in the presence of moisture, as acids, particularly mineral acids, attack the fabric, and alkalis have a saponifying action on cellulose esters and certain plastics. A great variety of fireproofing solutions for fabrics and fire-resistant dopes has been submitted to the Bureau of Standards for examination. The best treatment for fabrics has been found to be a 10 per cent solution of ammonium phosphate neutralized with ammonia. This has been found to exert no deleterious action on fabric or dope. Soluble chlorides in general have been found to weaken the fabric.

Several pigmented fireproofed dopes have been examined. The pigments used consisted of finely ground ammonium phosphate or magnesium-ammonium phosphate. These were incorporated in suitable proportion in a state of fine division in a nitrate dope. The dope is applied alternately with clear dope, one coat of pigmented dope on the fabric, then clear dope, then pigmented, etc., five coats in all. A pigmented varnish is applied over the dope.

Several fireproofed dopes resembling an English product called "titanine dope" have also been submitted. These consist of nitrate dopes containing chlorides of zinc, calcium, or magnesium added in alcoholic solution. The hygroscopicity of these salts is objectionable, and such dopes tend to become slack on the fabric in humid weather. This can be overcome in part by laminating the dopes between coats of clear dope.

Nitrate dopes may also be fireproofed by incorporating tricresyl phosphate or hexachlorethane in the dope film. The former compound is preferable and forms a better solid solution with cellulose nitrate than triphenyl phosphate. It is necessary to fireproof the fabric when dopes of this type are applied.

Relation of Dopes to Fabrics

It has been previously stated that shrinkage is caused by a film of cellulose acetate or cellulose nitrate embedded in a fabric and drying from solution. Silk is a continuous fiber, and linen is characterized by staple, and no trouble is experienced in obtaining shrinkage with fabrics made of these fibers. When ordinary cotton fabrics are doped, the shrinkage is poor and may not result at all. Cotton of the longest staple obtainable has a short fiber when compared with silk or linen. The cotton fibers, under the tension of the dope film, appear to slip, or since the cotton fiber has the appearance of an evacuated rubber tube and is twisted rather than straight, the cotton fiber under tension becomes straightened. The total effect of the behavior of the individual fibers is a refusal on the part of the fabric to respond to shrinkage.

The cotton airplane fabric developed by the textile section of the Bureau of Standards and adopted not only by this country but by England, was constructed of long-staple cotton, mercerized in the yarn without tension. Mercerization not only changes the physistructure of the cotton fiber, but also appears to have a cementing action owing to the decomposition of sodium cellulose by water. The resulting fabric responded to shrinkage excellently, and could be manufactured from raw material produced in this country.

It is necessary that the fabric be made of long-staple cotton. When short-staple cotton is used, the fibers of the fabric are slightly untwisted and raised by the doping brush. When the dope film is dry, these small fibers project through the film or are buried in it, producing hills and hollows on the surface. When enamel is applied over the dope, the surface of the fabric has the appearance of "gooseflesh" and is very rough under the hand. This is objectionable, because skin friction is abnormal when the plane is flying, and maximum speed is impossible.

BALLOON GASES

Compilation of Information

Even before the beginning of the war and during the entire time that the United States was engaged in the conflict, the Bureau was frequently consulted by both the Army and the Navy regarding a great variety of technical facts connected with the production, storage, properties, analysis, and use of balloon gases, particularly hydrogen. Many of these questions required extensive study, and it is possible to mention here only the more important of them.

At the request of the Navy Department a critical study was made and an extensive report rendered on methods of generating hydrogen practicable for use on shipboard. Later a conference was held and recommendations were made for the generation of hydrogen for signal balloons to be carried by seaplanes.

An extensive bibliography of the scientific literature relating to helium was prepared at the request of the Navy Department as an aid in the development of this gas for military purposes. This bibliography has been published by the Bureau as Circular No. 81.

A large part of the "Hydrogen Manual," a general handbook upon the production, properties, handling, and use of hydrogen, published by the Navy Department, was prepared or edited by the Bureau of Standards.

Reports were issued upon the "Influence of Water Vapor in Hydrogen upon Lifting Power of the Gas," upon "The Effect of Oxygen in Balloon Gas," and upon the compressibility of hydrogen, the latter report being used in the purchase of hydrogen from the manufacturers.

Laboratory and Field Work upon the Generation of Hydrogen

At the request of the War Department, the Bureau undertook a comprehensive study of the generation of hydrogen by the reaction between sodium hydroxide and ferrosilicon. This study included a thorough laboratory investigation of the fundamentals of the process for the purpose of determining the best materials and methods to be employed in the process and a less-complete investigation of the equipment used in the field. This investigation was covered by no less than five reports issued at various times. The more important results obtained are given in report No. 40 in the Fourth Annual Report of the National Advisory Committee for Aeronautics. It was shown by the work of the Bureau that about 60 per cent of the sodium hydroxide formerly used in the method could be saved. This represents, in the aggregate, a large saving of money to the Government. The present practice of both the Army and Navy in carrying out this extensively used process is based upon the investigation made at this Bureau, as are also the specifications for the materials used.

Tests of Hydrogen Plant at Langley Field

The final tests of the purity and quantity of hydrogen produced by the $200 000 hydrogen plant at Langley Field, Va., were made by this Bureau, after the contractors and the inspectors for the Signal Corps had failed to reach agreement. Acceptance of the

plant and the amount of compensation rendered the builders were based upon this determination.

Inflammability of Mixtures of Hydrogen and Helium and the Ignition of Balloons by Incendiary Bullets

A laboratory investigation was made to determine the amount of hydrogen which could be added to helium in balloon practice without losing the advantage of noninflammability. In order to have the information ready as soon as helium should become available as well as to avoid the use of larger quantities than necessary of so expensive a gas, the inflammability of hydrogen and nitrogen mixtures was first investigated with especial reference to the ignition of jets of the gas issuing from an orifice such as would be made in a balloon fabric by an incendiary projectile. This preliminary study with nitrogen made unnecessary more than very brief and inexpensive experiments with helium, and the required data were ready well in advance of any immediate need for their application.

The Bureau also cooperated with the Air Service in making a study of the ignition of hydrogen balloons by means of incendiary bullets. Several hundred experiments were made under various conditions and with a variety of incendiary bullets upon hydrogen bags made of balloon fabric. These bags and other facilities were prepared by this Bureau.

Gas-Leak Detectors

At the request of the Signal Corps a laboratory investigation was made of instruments for the purpose of detecting leaks in balloons, and a report was rendered recommending the use of a particular type of instrument commercially available. The recommendation is understood to have been followed by the Air Services of both the Army and Navy.

Means for Determining the Specific Gravity of Balloon Gas

An apparatus was designed and a model constructed at this Bureau for determining the specific gravity of balloon gas. This apparatus has been adopted by both the Army and Navy. Some of the essential parts of the first 50 instruments placed in service were also made at this Bureau, but the apparatus is now supplied by a commercial instrument maker.

CALIBRATION OF TESTING MACHINES

The purchase of immense quantities of war materials under specifications which prescribed minimum physical requirements

necessitated the employment of numerous testing machines at manufacturing plants for the use of Army and Navy inspectors. In order to make sure that the results obtained by these machines should be sufficiently accurate, it was necessary to calibrate them and check their readings against those of some machine of known accuracy at a central point. In order best to carry out this work, the chief of the engineering materials section of the Bureau of Standards was appointed advisor of physical control for the Ordnance Department of the Army in 1917. The Bureau acted in a like capacity for numerous other Government departments during the war.

Comparison Bars for Calibration

The major part of the Bureau's work in testing machine calibrations consisted in the tensile testing of "comparison bars" for the purpose of comparing certain loads on manufacturers' machines with the machines at the Bureau. The accuracy of the latter has been determined by dead-weight calibrations, but this method is unsuited for use on machines a long distance away owing to the difficulty of transporting the necessary weights and levers. The comparison-bar method depends for its accuracy on the uniformity of the steel in the bar from which the tensile specimens are cut and also upon the accuracy of the tests in both machines. The usual way in which such a test is carried out is as follows: A bar of steel is cut into sections which are numbered consecutively, tensile specimens are machined from the sections, and alternate ones are pulled in the standard machine and the others in the machine which it is desired to calibrate. The method is not recommended, and the Bureau will give no certificate of accuracy for a machine calibrated in this manner. It was realized that this method of calibration was merely a makeshift, but it was necessary to employ it in the war emergency.

Preferable Calibration Methods

Preferable methods for conducting calibrations of universal or tensile testing machine are by calibration bars, by proving levers, or by direct dead-weight loading, the last, of course, being the most accurate, but usually impracticable for large capacity machines. Calibration bars, as distinguished from comparison bars, are stressed repeatedly over ranges not exceeding the proportional or elastic limits of the material. An extensometer is attached, preferably in some permanent manner, and the deformation readings as observed on either machine serve as a basis

for comparison. It is clear that this method verifies the accuracy of the testing machine over a larger portion of its range and it also possesses marked advantages from a number of other aspects. The proving levers employ dead weight, but with a multiplying lever device so that the weights which must be transported with the machine are not so heavy as to be prohibitive. However, even this device is too large and expensive to be practicable for most of the calibration work such as was carried out during the war. All of these calibration methods were resorted to by the Bureau on various occasions in response to requests from the Army and Navy. At the present time experimental work, which was laid aside during the war due to the pressure of military investigation, is now in progress; it will provide a calibration apparatus having a capacity of 100 000 pounds and an accuracy sufficient for all commercial requirements.

Hardness Machines and Extensometers

Beside the work outlined above on tensile and universal testing machines, the Bureau's calibrations also cover a number of hardness-testing machines of the Brinell and scleroscope types. A Brinell meter, designed to furnish a portable hardness-measuring machine, was studied. Experimental data justified its recommendation for all purposes where a variation of ± 5 per cent from the reading which would have been obtained on the ordinary hydraulic or dead-weight testing is allowable. The Bureau likewise conducted a rather extensive investigation of the accuracy of various instruments for measuring the deformation of tensile specimens under progressive loading. It was decided that a certain make of extensometer was unsatisfactory for a determination of the elastic limit where successive applications and releasings of the load are required, or for the determination of the modulus of elasticity, but would probably be satisfactory for determining the yield point or for approximate determination of the proportional limit of the material.

CHEMICAL INVESTIGATIONS (MISCELLANEOUS)

Ferrous Materials

The work on the above subject consisted chiefly in the analysis of material required by the various branches of the Army and the Navy, and in supplying information to other divisions of the Bureau in their investigations, or developing suitable materials for the various military needs. It was necessary that these results be

furnished as accurately as the case required and with the least possible delay.

Several branches of the military service detailed chemists to the Bureau for their tests, working under the direction of members of the Bureau's staff. Naturally this created a delicate situation requiring much care and thought to maintain proper adjustment, but it is believed the situation was satisfactorily met. Ultimately separate laboratories were established by these military branches at points nearer the source of production, though the Bureau's laboratories were still called upon for check and control analyses.

Under the stimulus of war needs, many new alloy steels were produced and submitted for tests; also materials obtained by our special agents abroad were sent to the Bureau for examination. It was necessary to make careful analyses of these materials to determine their composition, not only of the ordinary elements, but also of unusual alloying elements, and to develop methods of analysis and to study their influence on the standard determinations ordinarily used.

The regular methods for the determination of molybdenum and vanadium have been modified so as to apply to many of the alloy steels. The accuracy of the determination of silica in ferrosilicon has been tested under varying conditions, and a quick method for the determination of chromium by persulphate oxidation has been investigated.

The persulphate method for the determination of manganese was found not to be applicable to steels containing over one-half per cent chromium, and the end point was masked by high content of nickel. Cobalt up to 20 per cent was found not to interfere with the determination of nickel by the glyoximine method. More concordant results were obtained on the determination of carbon in nichrome by direct combustion than by solution in double chloride of potassium and copper.

Nonferrous Materials

The work in this laboratory is very similar to that of the ferrous laboratory, consisting chiefly in the analysis of material required by the various branches of the military service and in the supplying of information to the other divisions of the Bureau to aid them in their investigations to determine the most suitable materials for the various military needs and to explain causes of failure.

In the study of light-weight alloys for aircraft construction the effect of small additions of various elements to aluminum required a special study to develop suitable methods of analysis.

While the major part of these investigations were of a physical or metallurgical nature, knowledge of the composition was most important, not only of unknown alloys, but also of alloys made on definite formulas to measure segregation and losses.

In many of these alloys unusual elements or combinations of elements occurred which necessitated a study and adoption of methods to each particular case. Some of the cases may be mentioned:

It was found that in some cases nickel failed to deposit. Some experiments were made on known solutions containing chromium, vanadium, and uranium salts; in these cases nickel deposited only partially or not at all. It was found that large amounts of ammonium sulphate had no effect on the deposition of nickel. Iron and manganese have little or no effect, so it was necessary to remove chromium, vanadium, and uranium before depositing the nickel.

When zinc is the only impurity in appreciable quantities in tin, difficulty is experienced in its separation. The most effective method found was to add pure lead or copper salts, and then separate all the sulphides together and in the mixed sulphides remove lead and copper electrolytically. So far, this plan works effectively.

It was found that zinc could be removed from aluminum in 0.01 N solutions of sulphuric acid. The same method can be used effectively for separation of large amounts of zinc from nickel. Recent experiments indicate that ammonia can be used instead of sodium hydroxide, thus eliminating impurities in sodium hydroxide.

Considerable work has been done in aluminum solders. These vary greatly in composition, and methods must be varied accordingly. In alloys high in tin, the tin was determined electrolytically from oxalic-acid solutions. Considerable work was required to determine proper conditions, and further study is required before all points will have been covered.

The failure of nichrome tubes used in calcining gas-mask carbon has been studied. No satisfactory method for the analysis of this alloy was found in the literature and much difficulty was encountered in the determinations required. Satisfactory methods show a marked difference in various parts of the tubes, but it is still impossible to say if these variations are due to segregation in the original tube or resulted from their use.

The separation of small quantities of cobalt and nickel is required in the analysis of some of the new alloys, and methods are being studied to this end.

Platinum Metals and Platinum Substitutes

A chemical laboratory for the study of platinum and the metals associated with it was organized in this Bureau in July, 1917. In conjunction with other laboratories of the Bureau its purpose was to prepare the pure platinum metals and their alloys, study their chemical and physical properties, and develop the analytical methods for the group.

Opportunities for rendering assistance in the prosecution of the war soon became apparent. Work for the nitrate division of the Ordnance Department of the Army came first in order and soon occupied a position of first importance. Platinum wire woven into gauze was used in large quantities as a catalyzer in the oxidation of ammonia to nitric acid. Much experimental work as to the size of wire, mesh of gauze, and purity of the platinum necessary to obtain the highest efficiency had to be carried out. The first two of these items were handled principally by the nitrate division, but several of the gauzes used were examined by the division of weights and measures of this Bureau for size of mesh and regularity of weave.

There was considerable uncertainty as to the effect of small amounts of rhodium, iridium, palladium, iron, and other metals alloyed with platinum on the efficiency of the latter for catalytic purposes. It was claimed by some authorities that the platinum must be specially free from iridium. As this element, together with rhodium and iron, is almost always present in commercial platinum, it was necessary to be able to obtain accurate analyses of the platinum used. The methods used were based for the most part upon those employed by Deville and Stas in the analysis of the platinum-iridium alloy used in the international standard mete. Their method gave very accurate results for iridium. The separation of rhodium and platinum by potassium pyrosulphate fusion proved extremely tedious, and a primary separation by distillation in a current of carbon monoxide and chlorine, as recommended by the German Reichsanstalt, was later adopted. Iron was best determined colorimetrically on a separate sample. Complete analyses were made on several gauzes the efficiency of which had been previously determined. Some iridium determinations were made on material refined for the nitrate division by the New York Assay Office.

An attempt was made by the optical division of the Bureau to determine small amounts of impurities in some of the samples submitted by the nitrate division by spectroscopic methods.

Owing to the lack of standard alloys this proved unsatisfactory. Occasionally use was made of a rapid method for an approximate determination of the total impurities which was developed by the metallurgical division of the Bureau (Scientific Papers Nos. 254 and 280). This method depends upon the emf developed at a hot junction of a platinum alloy with pure platinum. Some of the determinations were made by the metallurgical division.

Another section of the last-named division made metallographic examinations of some of the gauze before and after being used in the oxidation of ammonia. The results obtained were helpful in determining the phenomena which occurred in the catalytic process.

In addition to the work already described the chief chemist of the Bureau served the nitrate division of the Ordnance Department in an advisory capacity on numerous questions relating to the sources and supply of platinum and the assay of platinum ore received from Russia. The nitrate division in turn cooperated with the Bureau by detailing a member of their chemical staff to work in the platinum laboratory and furnishing funds for part of the necessary equipment.

In the latter part of 1918 problems of a similar nature to those already outlined arose in the Bureau of Aircraft Production. One complete analysis was made on platinum-iridium contact points for airplane magnetos. Later the electrical division of the Bureau undertook a study of the relative efficiency in service of magnetos equipped with contact points of varying iridium content. This was done in order to determine the possibility of economizing on iridium, the available supply of which was very low. Magnetos for several different types of engines were tested. Determinations of the iridium and iron content were made on all the types of contact points used. It was found that the iridium content fell somewhat over 50 per cent short of specifications in each type. This rendered the results of the whole series of tests only partially useful. The manufacturer of the contact points proposed to make up a new set of alloys, but the second series of service tests was not undertaken owing to the termination of hostilities.

The shortage of platinum a short time before and during the war aroused the interest both of commercial organizations and the public in general. Quite a number of "platinum substitutes" were developed, and many samples of supposed platinum ore were

submitted to various Government laboratories. A few of the latter were examined by this Bureau. None of the samples submitted showed any platinum. The most interesting case was of a mineral from the Grand Canyon, which was repeatedly brought forward as a source of platinum in spite of the statement from the Geological Survey that it contained no precious metal. New samples were taken by the Survey and assayed in their own laboratory, that of the Mint, and of this Bureau. No platinum could be found. A more detailed report of this investigation is given in Mining and Scientific Press (**118**, p. 185; 1919).

The substitutes proposed for platinum were of two kinds, those composed of base metals and alloys of the noble metals. Of the latter, two were examined, known as rhotanium and palau. Both are alloys of gold with relatively small amounts of palladium. These were tested in conjunction with the metallurgical division of the Bureau and were found suitable substitutes for platinum in numerous operations in the chemical laboratory. A detailed report of these tests was published in the Journal of Industrial and Engineering Chemistry.

In the case of the base-metal substitutes none was found which approached platinum in general usefulness. In one case steps were taken to suppress extravagant advertising. Two alloys were examined which were found suitable for the purposes for which they were designed. One was an alloy very resistant to nitric acid and the other could be used for electrical contact points under a limited range of conditions. The former was submitted by the nitrate division of the Ordnance Department, but the greater part of the work on platinum substitutes was done for the platinum section of the War Industries Board.

Prevention of Corrosion

The work of the Bureau has included a study of the corrosion of metals and its prevention. The tests were generally made by the salt-spray method, originally described by J. A. Capp (Proceedings of the American Society for Testing Materials, **14**, part 2, p. 475) and greatly improved in the Bureau's laboratory, as described in Proceedings of the American Society for Testing Materials (**18**, part 1, p. 237, 1 918). It is thought that this test indicates, in an accelerated way, the relative resistance to corrosion of metals, especially when exposed to saline conditions. Tests on corrosion of aluminum, undertaken chiefly in the interest of aeronautics, were made on alloys of aluminum with copper, nickel, manganese, and

magnesium prepared by the metallurgical division of the Bureau. The following conclusions were drawn:

(1) A decided difference in resistance to corrosion may be produced by quenching some aluminum alloys; (2) a less marked difference is produced by annealing; (3) with some alloys no apparent difference is produced; (4) if any change is produced by quenching, it improves the quality of the metal; (5) the magnesium, nickel, and nickel-magnesium alloys have about the same resistance to corrosion regardless of heat treatment; (6) annealing improves somewhat the quality of the copper-magnesium alloys and reduces the quality of the manganese-magnesium alloys; (7) quenching produces the most desirable effects in the copper, copper-magnesium, and manganese alloys; (8) commercial aluminum, as rolled, does not resist corrosion satisfactorily, and the sample tested was almost completely disintegrated at the end of the test; annealing or quenching materially improves it, but it is not equal to some of the alloys.

In developing the data on which these conclusions were based and in other tests, it is noteworthy that ordinary sheet aluminum as rolled frequently exfoliates, showing a laminated structure instead of a homogeneous mass.

The various types of zinc coatings were tested and no evidence was obtained to indicate superiority of hot galvanizing, sherardizing, or plating. The use of zinc was recommended for protection of iron or steel against corrosion wherever its application was possible, the value of the coating (or protection afforded) being judged by its life in the salt spray or amount of zinc applied per unit area, depending on conditions of exposure anticipated in service. This report is covered in more detail in the report on "Protective Coatings," appearing elsewhere.

Corrosion produced by the use of soldering fluxes was also considered. For general purposes the use of zinc chloride fluxes seems to be almost universal, and although they will undoubtedly accelerate corrosion, their use seems to be unavoidable. Rosin was recommended whenever it could be used, and if zinc chloride was used, thorough washing with hot water was advised.

Examination of hydroplane radiators indicated that leaks which develop in storage are caused by corrosion accelerated by the zinc chloride flux which was left on the metal. Washing inside and out with hot water and sodium carbonate solution was recommended as a probable means of correcting this difficulty.

Removing Metal Fouling from Rifle Barrels

Prior to the war, a solution made according to the following formula was used for removing the cupro-nickel fouling from rifle and machine-gun barrels:

Ammonium persulphate	ounces	1
Ammonium carbonate	grains	200
Water	ounces	4
Ammonium water (28 per cent)	do	6

In September, 1917, the office of the Chief of Ordnance of the Army found that not enough ammonium persulphate was produced in the entire country to supply the needs for cleaning rifles, and requested this Bureau to recommend a substitute.

At this time there appeared to be only a shortage of ammonium persulphate, and numerous experiments were made in trying to find a satisfactory substitute for this chemical. Nothing was found which at all met the requirements. While these experiments were still in progress it developed that the supply of ammonia water was becoming depleted and that no further supplies of this substance could be relied upon.

At this stage of the investigation, an electrolytic method for cleaning the barrels was successfully developed. This was quite simple and consisted in using an electrolyte made of a mixture of sodium carbonate and ammonium sulphate dissolved in water, a steel rod being used as the anode and the rifle barrel forming the cathode. The experiments with this method demonstrated that in using a current of about 0.5 ampere and from 4 to 5 volts, cleaning was more rapid by the electrolytic method than by the use of the old persulphate solution.

It is believed that the ordnance officials developed an apparatus for generating the required electric current for this work, and it was submitted for approval. The electrolytic method had the objection of requiring a source of electric current, either from a central station or from batteries, and hence could not be satisfactorily used except at base stations. The method would, however, probably have been introduced had it not developed—middle of December, 1917—that a sufficient supply of ammonium persulphate would be available.

The ordnance officers deemed it advisable, however, to eliminate the use of liquids which would have to be transported, thus necessitating avoiding the use of ammonia water. After making numerous experiments, it was found in December, 1917, that a mixture of 3 grams of ammonium persulphate, 5 grams of am-

monium sulphate, and 2 grams of caustic soda dissolved in water to make 35 cc was quite efficient in dissolving cupro nickel and had no appreciable injurious effects on the steel. Such a mixture had distinct advantages; the reagents could all be kept in a solid form, and it was suggested that the ammonium persulphate and ammonium sulphate could be prepared in solid tablets which could be kept in glass, metal, or cardboard containers. The sodium hydroxide could also be kept in metal or glass containers. It would then be very simple to make up the solution by dissolving the requisite number of each kind of tablet in water and mixing the solutions for use.

Ordnance officers took up the question of making contracts for tablets and found that it would be necessary to use a small amount of binding material, such as sugar, and a lubricant similar to stearic acid or paraffin, in the manufacture of the tablets. The amount of these additions was small, and specifications were finally drawn up for these tablets and have been issued by the War Department.

Soap

A number of different brands of shaving soaps (including stick and cream) were examined by the Bureau for the purchase, storage, and traffic division of the War Department during May and June, 1918. Following this examination, specifications for stick shaving soap and shaving cream were drawn up by the Bureau and submitted to the War Department.

Numerous analyses of laundry soap have been made for the same department during the same period.

Carbon Tetrachloride Fire-Extinguishing Liquid

At the request of the War Industries Board and the Quartermaster General of the Army experiments were made to find a substitute for chloroform as freezing-point depressant in carbon tetrachloride to be used as a fire-extinguishing liquid. It was found that gasoline and turpentine were both efficient freezing-point depressants of carbon tetrachloride, and that the resulting mixtures were fire-extinguishing liquids. The signing of the armistice removed the demand for conserving chloroform, and hence the mixtures suggested were apparently not used.

Antifreezing Solutions for Automobile Radiators

The question of a satisfactory antifreezing solution for radiators used in connection with gasoline motors was studied. The chief constituent of all antifreezing compounds tested was cal-

cium chloride, and numerous tests showed that the corrosion produced by their use was decidedly rapid, particularly at soldered joints in radiators and on all-aluminum parts which are used in some engines. Whenever solutions of calcium chloride get on the ignition system, either from leaks or overflow, electrical leaks or short circuits are produced which interfere with engine performance, and such electrical leaks are very difficult to correct.

The use of alcohol and water was recommended for trucks, automobiles, etc., but such solutions have a peculiar limitation when used on aircraft, that of a low-boiling liquid for high altitudes. Tests were undertaken and are still in progress to determine if the addition of glycerin to such a solution will overcome this objectionable feature.

Prevention of Foul-Gas Formation in Ammonia-Absorption Refrigerating Machines

A problem started before the war, but which assumed added significance shortly after the beginning of hostilities and which was, therefore, pushed to completion, was the causes and means of prevention of foul-gas formation in ammonia-absorption refrigerating machines. On account of the scarcity of ammonia during the war and the large losses necessitated in purging a plant of foul gas, the solution of this problem was of considerable importance, as it helped toward the conservation of ammonia. It was found that the main causes of this trouble were leaks of gas into the system and the gas produced by the corroding of the metal in the plant by impure aqua ammonia. This latter cause was entirely prevented by the addition of sodium dichromate to the charge of aqua ammonia. The results of this work have been published in Technologic Paper No. 180, "Causes and Prevention of the Formation of Noncondensible Gases in Ammonia Absorption Refrigeration Machines."

Development of Automatic Analytical Apparatus for Use in Nitrate Plants

During the summer and autumn of 1918 a force of about 15 men was engaged upon the problem of designing and building an automatic apparatus for the continuous analysis of the gas mixtures of widely different character occurring in the contact process for the manufacture of ammonia. This apparatus was regarded as essential to the efficient operating control of the large nitrate plant projected at Mussel Shoals. At the signing of the armistice one unit of this apparatus capable of automatically making and

recording in series 12 different analyses was nearly ready for installation. A smaller unit for the same purpose was provided for the laboratory engaged upon the fixed-nitrogen research. While this work did not reach the stage of application to the purpose for which it was intended, the methods developed, which are largely new, should find extensive application in many industries.

Hydrogen Detectors for Use in Submarines

The problem of designing a suitable hydrogen detector to prevent the accumulation of a dangerous amount of gas in submarines was presented to the Bureau as the result of two serious explosions prior to the war. Ten or more devices for the same purpose, designed and constructed outside the Bureau, were submitted to the Bureau for tests and criticisms. An apparatus believed to be satisfactory for the purpose was designed at the Bureau and, after extensive laboratory tests, was submitted to the Navy Department. The tests upon the instrument made in the New York Navy Yard were reported to be entirely satisfactory, and 60 of the instruments were constructed and calibrated. The severity of the mechanical and electrical conditions to which they were to be subjected was underestimated, however, and they did not render satisfactory service. Another type of instrument was then designed especially to meet the most severe conditions of service, even at a sacrifice of several of the desirable features of the earlier device. This instrument has been tested by the Navy Department and reported upon favorably, but has not yet been placed in production for use aboard ship. The earlier work along this line is reported in Scientific Paper No. 334 of this Bureau.

Determination of Carbon Dioxide and Oxygen in the Air of a Submarine

Much time was devoted to the problem, initiated by the Navy and transferred to this Bureau by the Sanitary Corps, of automatically indicating the percentage of carbon dioxide and oxygen in the air of a submarine. This problem appeared to be well on the way to solution when the Bureau was informed that it was no longer regarded as of much importance, and it was abandoned for more urgent work.

Tests of Gas Masks and Oxygen-Supply Apparatus

Tests were made and recommendations reported regarding the use of gas-supply apparatus for aviators when more than one man was to be supplied from the same source. Prior to the organ-

ization of the Chemical Warfare Service this Bureau also did the preliminary work of examining the gas masks used by European armies. This work included the identification of the materials used as absorbents and testing the resistance to respiration and other mechanical features of the masks.

Miscellaneous

A great many gasolines and gasoline substitutes were examined in connection with the work on airplane engines. Castor oils were investigated quite frequently for the Signal Corps, and miscellaneous materials, including neat's-foot oil, saddle soap, and white floating soap, were examined for the Ordnance Department.

CHROMATIC CAMOUFLAGE AND CHROMATICALLY CONCEALED INSIGNIA

Owing to the fact that different spectral distributions of light may give the same color, it is possible to have samples accurately color-matched as examined by the unaided eye in daylight, and still show glaring chromatic contrast when examined through suitable light filters (colored glasses, etc.). This circumstance was a source of danger to the camouflage artist. For example, a fabric might be dyed green to closely match green foliage, and through a properly chosen filter it might appear bright red on a dark green or black background of normally green foliage. Indeed, it might be about as conspicuous as a fire at night. On the other hand, it might, through another filter, appear dark on a bright red background of normally green foliage.

At the request of the War Department, the Bureau made several tests of materials in this respect and was able to recommend dyes and select fabrics to overcome this difficulty.

The Bureau itself did not undertake a comprehensive and unified investigation of the subject of "camouflage." However, a great deal of work bearing on it was done at the request and instigation of others working on these subjects. A great deal of oral information on ray filters, spectral transmission, and reflection and chromatic camouflage, often illustrated by experimental demonstration, was given to officers of the Army and Navy and representatives of the National Research Council. Ray filters were lent from stock, and others were made to order of prescribed properties and supplied to the applicants for them.

The Bureau was also asked to investigate the practical possibilities of chromatically concealed insignia; that is, insignia woven, painted, or made in such a way that they would be invisible to the

unaided eye in daylight and be rendered visible by examination through properly selected filters. Many combinations of dyed fabrics were prepared which were nearly or quite indistinguishable to the unaided eye, but showed remarkable color differences when examined through suitable filters. These were exhibited and explained to numerous representatives of the War and Navy Departments. An exhibit of some of these was made in connection with the American Physical Society exhibit at the Bureau, April 25 to 26, 1919.

COKE-OVEN INVESTIGATIONS

During the latter part of 1917 the attention of the Department of Commerce was directed to the Roberts coke and gas oven through the efforts made by the American Coal & By-Products Coke Co., the owners and operators of the Roberts process, to secure Government support for this enterprise. This matter was referred to the Bureau of Standards for action.

Preliminary Work of the Bureau

Since there were 24 Roberts ovens in operation in Canal Dover, Ohio, three representatives of the gas engineering section of the Bureau were detailed to inspect the plant at this point and carried on their work on December 12 and 13. Two views of this plant, showing the general lay-out, are presented in Fig. 8.

The promoters of this process claimed a number of advantages for this oven which it was said were not embodied in other types. Among these were the following: (1) Ability to coke so-called noncoking coals and produce a satisfactory grade of metallurgical coke from high-volatile, midcontinent coals; (2) larger yields of by-products recovered than from other types of ovens; (3) more substantial construction than possible with existing types of ovens; (4) greater degree of flexibility of heat control than with existing types of ovens; and (5) increased earning power per oven over the other types of ovens.

At this investigation it appeared that the ovens were operating in a fairly satisfactory manner, and although the Bureau was not able to verify these claims to any great extent in such a short period, the indications were that the oven could be developed into a commercial success. Therefore, the Bureau of Standards reported to the Assistant Secretary of Commerce on December 15, as follows:

> We do not hesitate to recommend favorably this type of oven for further consideration for we feel sure that benefit to the Government and the people may be expected from the commercial development of the process.

Fuel Situation in Early Part of 1918

Early in this country's participation in the war it was realized that a successful end would be possible only through the intensive driving of our industries. This became particularly evident during the early part of 1918, and a great expansion of the steel industries of the country resulted. Likewise, it was realized that high explosives had to form a large part of the equipment of the American Expeditionary Forces. The rate of production of these necessary materials was limited to a great extent by the rate of the recovery of by-products of coal. The output of steel was curtailed because of the lack of iron, which in turn was not produced in sufficient quantities due largely to the lack of coke. The production of high explosives was not keeping pace with the growth of the armed forces of the Nation, because of the lack of fundamental materials—toluol, benzol, ammonia, etc.

In addition to the lack of coke-oven plants, climatic conditions during the winter months of 1917–18 greatly reduced the coal supplies of the existing plants. Transportation of large quantities of coal became increasingly difficult as the severe winter weather continued and as the railroads became choked with materials moving toward the seaboard. This particularly interfered with the maintenance of the production at full capacity on the part of the coke ovens in the central section of the country, since most of the existing plants in this section were dependent for their coal supplies upon so-called eastern coal. Likewise, with the increase of traffic more and more coal was used by the railroads and the use of raw coal in boiler plants and in other industrial activities, and in the heating of dwellings, factories, etc., due to the extreme cold and lack of other fuels, depleted the supply of fuels for these ovens.

Accordingly the utilization of much of the undeveloped fuel resources of the country became a question of paramount importance. Attention was forcibly directed to the large quantities of midcontinental coal available, particularly in Indiana and Illinois, but which was not being used. Inasmuch as the steel production of large plants, such as those at Gary, Ind., and Joliet, Ill., was sometimes reduced to 30 per cent through lack of coke, it was evident that some relief was essential.

Attention Focused on Roberts Oven

Since it was claimed for the Roberts oven that it was able to produce a first-class grade of metallurgical coke from these midcontinental coals, it was natural that this type of oven should be

looked upon as a proper agency to aid in the forestalling of the crisis which seemed imminent, as well as to assist in the development of these hitherto unused coal resources of the country. Therefore, using the Bureau's report of December 15, Mr. Roberts endeavored to interest the Government to aid in the further development of his process and to construct two plants, one at East St. Louis, Ill., and the other at Chicago, Ill., which would use coal from the Illinois (midcontinent) field, thus avoiding the long railroad haul and accelerating the production of coke, toluol, etc.

Test Conducted by the Bureau

Since the December 15, 1917, report of the Bureau was only a recommendation for further consideration, early in March, 1918, the Secretary of Commerce, acting by direct instructions from the President, ordered the Bureau to conduct an operating test of the Roberts oven installation at Canal Dover and to associate with itself the Bureau of Mines and the Geological Survey in this work. Accordingly, plans were immediately made for such a test, and representatives of the Bureau proceeded to Dover on March 18, but found that it was not feasible to begin the test at the time specified owing to a lack of boiler capacity.

The ovens at Dover were operating at this time on Cambridge (Ohio) coal, which, although somewhat similar to the midcontinent coals, bears a striking resemblance to the eastern coking coals.

It was decided, however, that the test should be condutced with the same coals which would be used at East St. Louis and Chicago; therefore the Bureau was instructed to assist in obtaining the necessary coal for this test, together with the required boiler parts. This the Bureau proceeded to do, but hindered by numerous construction and transportation delays, it was not until April 26 at 7 a. m. that the test was officially started. Quantitative observations of all parts of the plant operation were undertaken and were continued 24 hours each day, including Sundays, until 7 a. m., May 11. During this test 4800 tons of Illinois coal were used in the ovens and all of the usual by-products, including light oil, ammonia, and tar, were recovered and either carefully weighed or measured. The coal used was shipped from the Royalton, Sesser, and Orient mines in Franklin County, Ill., and the Ayrshire mine, Pike County, Ind. This work was conducted by 22 representatives of the Bureau of Standards and 9 members of the regular staff of the Bureau of Mines; 5 consulting engineers were also present at the request of the Bureau of Mines to advise concerning the work.

The Bureau's representatives were in charge of the test and responsible for observations of all work done about the coke oven, the by-product department, the light-oil department, and other accessory operations. Exact records were made of the charging and discharging of the ovens, the quantities of tar, ammonia liquor, light oil (containing benzol, toluol, etc.), and gas produced during the test period. Samples of all these materials were regularly taken, and analyses or tests of these samples made at appropriate intervals. Likewise, high-temperature measurements at various parts of the battery were carried on during the test.

The Bureau of Mines was responsible for the sampling of the coal at the mines, at which time record was made of the car numbers and weights of the coal shipped for the test. The Bureau of Mines also weighed and sampled for analysis the coal as it was unloaded in Dover for the test, thus identifying by car numbers and car weights the origin of the fuel used. The Bureau of Mines also was responsible for the sampling, weighing, and analysis of the coke produced from the test coal.

Because of mechanical difficulties the regenerators were not used during the test; therefore the ovens were not operated upon preheated air, but upon cold air. This precluded the making of any surplus gas, as it was necessary to use all that was obtained in heating the ovens. Difficulty was also experienced in the uniformity of the heating of the oven walls, the ends particularly being noticeably cold.

Results of Test at Dover

The coke produced from three of the test coals was satisfactory as to quantity and quality, the yield being substantially the same as that obtained from other by-product ovens. On the basis of dry coal, the yield of dry coke was 69.5 per cent, and the percentage of the sizes of dry coke to total coke were furnace size 75.1, nut 16.8, and breeze 8.1 per cent. A sufficient amount of coke was not produced by the ovens to operate the 500-ton blast furnace adjacent to the plant without the use of additional coke from other sources. Since the furnace was not able to operate at more than three-fourths capacity, and since the quantity of coke had to be increased by the addition of outside coke to the extent of from 30 to 50 per cent, it was impossible to determine the real metallurgical value of the coke. However, the opinion of the superintendent of the blast furnace was that when 100 per cent of this Illinois coke was used it would make a satisfactory blast-furnace fuel with the furnace at full capacity.

The yield of toluol both as to quantity and quality was good and amounted to about 0.43 gallon per ton of dry coal, and the yield of benzol amounted to 1.55 gallons per ton of dry coal. The yield of other by-products per ton of dry coal were as follows: Ammonium sulphate, 26 pounds; tar, 10.7 gallons; and gas about 10 000 cubic feet. However, on the basis of the quantity of these materials actually in the gas, the yields were somewhat higher than those quoted.

Conference at Pittsburgh

After the test at Dover was completed, a conference, which was arranged by the Bureau of Mines, was held in Pittsburgh on May 22, and the observations and results of the tests were discussed at length. Substantial agreement was reached as to what had been demonstrated by the test and what the results signified, and a report of this conference was made to the Secretary of Commerce on May 25, which was signed jointly by the Directors of the Bureau of Standards and the Bureau of Mines. The report was as follows:

> The Roberts oven produced a satisfactory grade of metallurgical coke from three of the four coals used. These coals have not heretofore been used to make metallurgical coke in commercial quantities. The gross yield was substantially the same as that obtained by other by-product ovens. The coke was mixed with about an equal amount of coke from other sources, because of the limited supply of Dover coke, and was used in a blast furnace running at about three-fourths capacity. A satisfactory grade of pig iron was produced. The superintendent of the furnace is of the opinion that he could operate satisfactorily with this coke alone and at full capacity.
>
> The quantity and quality of the gas produced was good. After removing the by-products all the gas was used in the process of coke making. An excess of gas will be available when regenerators are in successful operation.
>
> The quantity of by-products in the gas was good. The amount of tar, toluol, benzol, etc., in the gas was about the same as is obtained in other ovens when high-volatile coals are used and was greater than the average yield from low-volatile coal, or the usual mixture. The amount of ammonia in the gas was very good.
>
> The construction of the ovens is substantial. The heating system of the Dover plant leaves something to be desired in the matter of uniform heating of walls, and the regenerators for preheating air have not been in operative condition. Experience with the plant shows it can be improved in some particulars, and the company believes successful preheating of air and uniform heating can be demonstrated in a short time. It was necessary to run the test without regenerators, and, as their use is essential for most efficient operation under usual conditions and in normal times, this further demonstration is believed to be necessary.

The Roberts Co. immediately proceeded to carry out the agreed program for a further demonstration, but great mechanical difficulty was experienced in putting the ovens into shape for this purpose, and it was not until the latter part of September that it was possible to complete the work.

Further Work by the Bureau

The Bureau wished further to study the effect of temperature distribution in the various types of ovens, so that the feature of

greater uniformity and flexibility of heating, which Mr. Roberts claimed for his oven, could be either verified or disproved. Therefore a separate series of high-temperature measurements were conducted at Canal Dover during June, and similar tests were likewise carried out in the Koppers oven installation of the Laclede Gas Light Co., St. Louis.

The Bureau has also made an investigation of the existing patent literature and other literature on the subject of coke ovens, and prepared a report showing the development of the art of by-product coking of coal. This report has been given to several persons for criticism.

Interest in the Use of Midcontinent Coals Increased

During the period from May to October, 1918, other coke-oven companies had taken under serious consideration the use of these midcontinent coals in their particular types of ovens and had carried on experimental work. As a result, the Bureau received a request from the Koppers Co., of Pittsburgh, to conduct an operating test of the Koppers oven installation in the plant of the Minnesota By-Product Coke Co., St. Paul, Minn., which would be similar to that conducted at Dover in May.

At this time the Bureau was advised that 600 000 tons of Indiana coal had been used in the Gary, Ind., coke-oven plant, and received a report which referred to this occassion from G. C. Lowell, of Chicago, who mentioned it in the following manner:

> During the latter part of the year 1912, when there was a serious depression in the steel business, it was decided to charge a portion of the ovens at the Gary plant with 100 per cent of western coal. This coal was what was known as Clinton coal, coming from the Universal mines, located near Clinton, Ind. There was also a number of ovens charged with 100 per cent of coal from the Kelly mines located near Westville and known as Westville coal. This coke, made from 100 per cent of Indiana coal, was first produced with an idea of supplying a cheap coke to the blast furnaces at Gary that were supplying gas to the electric generating station, and no particular attention was paid to the yield of iron, it being attempted to hold the iron production to as low a figure as possible and produce a maximum quantity of gas.
>
> The coke was used in this manner for a few months, and when the iron production was again increased by the blast furnaces one battery of ovens was kept on the Clinton coal, and the coke produced from this battery was mixed with the regular coke produced at the Gary plant and charged into the blast furnace as mixed coke, using up to about 15 per cent of the Clinton coke in the blast-furnace charges. Fairly good results were obtained from the blast furnaces.

Test of Koppers Plant at St. Paul

Since such a long delay was experienced in placing the Roberts plant at Canal Dover in operating condition, the bureau acted upon the request of the Koppers Co. and secured permission from the President, through the Secretary of Commerce, to conduct an

extensive operating test of the plant at St. Paul. The Bureau of Mines likewise cooperated in this test, which was officially started at 7 a. m., September 27, 1918, and continued until 7 a. m., October 5, 1918.

The test of this plant, consisting of 65 Koppers coke ovens and all accessory equipment and apparatus for the recovery of all by-products, was conducted by 37 engineers and chemists, and in addition a considerable number of expert engineers visited the plant while the test was under way. The Bureau of Standards was responsible for the general planning and supervision of the test work. Its representatives made all observations of battery operation, high-temperature measurements, by-products recovery, and chemical laboratory work on gas and by-products. The Bureau of Mines was responsible for the sampling of the coal at the time it was loaded at the mines and for the weighing, sampling, and analysis of the coal as used at the plant, and of all sizes of coke produced. Its representatives also made general observations on the character of the coke and the operation of the ovens.

For this test 7600 tons of coal were used from the Orient mine, Franklin County, Ill. The quantity of all products was carefully weighed or measured at regular intervals, samples of each of the products were taken, and complete analyses of the coal and these products have been made.

Results of Test at St. Paul

The yield of dry coke was 68.4 per cent, and the percentage of the sizes of the coke on the basis of total coke were: Furnace, 56; domestic, 37.6; and breeze, 6.4 per cent.

The yield of toluol amounted to 0.54 gallon per ton of dry coal, and the yield of benzol to 2.29 gallons per ton of dry coal.

The yield of other by-products per ton of dry coal were as follows: Ammonium sulphate, 30.3 pounds; tar, 8.5 gallons; and gas, about 11 000 cubic feet.

Further Work at Dover

Immediately upon the completion of the St. Paul test, the members of the Bureau's party proceeded to Dover for the final demonstration of the Roberts process, with the regenerators operating. Since the War Industries Board had requested that a complete operating test be made with mid-continental coal, 1500 tons of Orient and 1000 tons of Ayrshire coal were secured for this test, and arrangements made whereby the coke would be stored until a sufficient amount had been accumulated, so that the blast

furnace could run for several days at full capacity on 100 per cent Illinois coke.

The test began on October 12, with the same methods pursued as were carried on in the May test, but before evening on October 14 the representative of the Roberts Co. requested that the demonstration be stopped, since the quality of the coke and the condition of the plant showed that it was not possible to make a successful demonstration at this time. The Bureau acceded to the request, and after conference with the War Industries Board, decided that until the company could demonstrate that the Roberts ovens could coke 480 tons of coal per day, the Bureau would not consider another test.

Blast-Furnace Test on St. Paul Coke

During the latter part of the work at St. Paul, arrangements were made to ship 1500 tons of the furnace coke produced to the blast-furnace plant of the Mississippi Valley Iron Co., St. Louis, Mo. Soon after beginning the use of the test coke in the blast furnace an additional quantity of about 360 tons was ordered. Of the total tonnage ordered, 1746 tons were actually used in the blast-furnace test. A representative of the Bureau of Standards was present during the period of the test, which started with the first charge of Illinois coke into the blast furnace at 1 p. m., October 19, and continued until 4.30 a. m., October 28.

This furnace was operating at a capacity of about 190 tons of iron per day and at the beginning of the test was making malleable iron. However, it was recognized that the most conclusive test of the merits of the coke would be obtained in making a run on basic iron.

From this test the following general conclusions were drawn by F. W. Sperr, jr., chief chemist of the Koppers Co., who was present throughout the test:

1. The coke was first-class blast-furnace fuel, which could be substituted directly for the regular coke (Laclede-Elkhorn) without creating injurious irregularity in operation.

2. The coke carried the normal basic burden well, with every indication that it would make any grade of foundry iron with the normal burden.

3. It was indicated that with the Illinois coke the consumption of coke per ton of pig iron is normal, and possibly even less than normal. This fact can not, however, be absolutely established in so short a test.

Great caution should be used in applying the results of this test and in predicting what Illinois coke might do if used on an older blast furnace of larger capacity or of different construction. The coal from which the coke used in this test was made represented

the highest grade of Illinois coking coals, and the results should not be too strictly applied to Illinois coke in general.

Additional Work Carried On by the Bureau

In order to determine the effect of variable temperatures upon the coking of Orient (Ill.) coal and upon the quality and quantity of gas made from this coal, a series of tests were run in an experimental retort of one of the large steel companies. These tests were five in number; the weight of the charge of coal in each test was about 4 pounds, and the temperature ranged from 835° C to 600° C.

The results of these tests in general show that the volatile matter in the coke increases as the temperature of coking decreases, and, correspondingly, with high-volatile matter in the coal, the yield of coke is high. However, at the lower temperature the percentage of fine material is much greater and the quality of coke very much inferior. In this connection, however, it should be noted that in none of the coking tests was it practicable to secure temperatures as high as are frequently used in oven practice with coals that are regarded as specially suited to the production of metallurgical coke. If high temperatures had been used another influence noted in connection with the St. Paul test would probably have appeared, namely, that at the high temperatures there is great tendency for the coke to be brittle, fingery, and small instead of tough and blocky.

By comparison of the results for the five tests, the very large influence of temperature of coking upon the quantity and quality of gas is evident. In this connection it should be noted that the high-temperature results represent not only a more complete eliminating of the volatile material from the coal but also a decomposition of the heavier volatile material into gaseous constituents. Naturally as the vapors leaving the coal are subjected to this greater decomposition at higher temperature, the average heating value of the gas is diminished. This diminution of heating value per cubic foot is, however, by no means enough to offset the effect of the larger volume, as is shown by the fact that the British thermal units in the gas per pound of coal carbonized at 840° C is almost double that at 600° C.

Conclusions

From the investigation of these subjects by the Bureau of Standards the following facts have been demonstrated:

1. At least the majority of the coals from Franklin County, Ill., and some from Pike County, Ind., located in the mid-continent

field, can be coked in by-product coke ovens, and a fairly satisfactory grade of metallurgical coke can be produced. Likewise by-products of reasonable quantity and good quality can be obtained from these coals.

2. The Roberts process at the time of these tests was still in the development stage, but credit should be given to Mr. Roberts for his work in connection with the coking of these coals. His efforts along these lines undoubtedly did much toward arousing interest among other coke-oven operators looking toward the use of midcontinent coals.

3. The Bureau believes that at least some of the coal from the midcontinent field should be used in the coke-oven plants in the central section of the country. Even though the coke, on the whole, proved not to be uniformly as satisfactory as that from the so-called coking coals, the advantage due to the elimination from the coke-oven plants in the eastern section will go far in overcoming any lack of quality of the coke. There can be no doubt that where domestic coke is wanted these coals can fulfill all requirements. Such uses will materially aid in the proper development of the fuel resources of the country.

The results of the investigations conducted at the Koppers plant are embodied in Technologic Paper, No. 137.

CONCRETE AND CEMENT

Concrete Ships

This subject is treated separately, under the above title in another part of this report.

Load Tests of Concrete Floors of Arlington Building

On account of the vast amount of work connected with insurance carried by our soldiers during the recent war with Germany, it became necessary to increase the personnel of the Bureau of War Risk Insurance. In order to do this more room was required, and it was decided to use the new Arlington Building which was not yet completed.

This building is constructed with System "M" steel framing and with a well-known type of hollow-tile floors. In order to determine its degree of safety and also the desirability of erecting other Government buildings on this system, the Treasury Department requested the Bureau of Standards to conduct a loading test upon various portions of the structure. No prior loading test on this type of construction is known in which strain-gage measurements were taken.

The load tests were planned to determine the maximum live load which could be applied to individual panels and to determine the stress of the beams and columns of the System "M" construction.

The original plans of this building were changed so as to make the structure, which was intended for a hotel, suitable for a Government office building. The design was modified so as to provide for a live load of 100 instead of 74 pounds per square foot.

The specifications were changed to require a 2-inch layer of concrete above the tile to care for this additional live load, and the amount of steel was also increased.

The investigation comprised strain-gage readings of deformations and corresponding deflection readings when loads were applied by piling bags of cement on the panels tested. Deformation readings were taken with Berry strain gages on the embedded structural steel and also on the concrete and tile.

The reduction of the experimental data involved the making of temperature corrections and the changing of observed strains to corresponding stresses by the employment of the proper modulus of elasticity, as determined from laboratory tests on sample materials. Curves were plotted showing the relations between the load on the panels and (1) the steel stress, (2) the concrete deformation, and (3) the panel deflection; also between the magnitude of the stress or deformation and its position on the panel. The elastic curves of sections of the panels, as determined from the deflection readings, were also drawn.

Numerous fallacies in this system of construction were disclosed. The mathematical development was found to be in error in several places. For a square panel simply supported on four sides, the formula used by the designers gives a value for the bending moment along the diagonal, which is one-third that obtained by the use of the formula in the report of the Joint Committee on Concrete and Reinforced Concrete. The latter is logically developed from the laws of statics, and the illogical steps in the development used for this construction were pointed out by the Bureau.

The test results disclosed continuity of the beams in the Arlington building which had been designed to function as simple beams. In another case a maximum concrete stress of 1909 pounds per square inch, at twice the designed live load, was found due to the misplacement of continuity bars. In still other cases compressive stresses as high as 1310 pounds per square inch, at twice the designed live load, were found in the concrete. Con-

crete stresses were computed by the use of a value of 2 500 000 pounds per square inch for the modulus of elasticity. Tile stresses as high as 1600 pounds per square inch at three times the designed live load, were found by using 3 500 000 pounds per square inch as the modulus of elasticity of the tile. Maximum stresses of about 25 000 pounds per square inch were found in the steel in the center of the panel and also in bars in the beams, at twice the designed live loads.

While not indicating a dangerous condition in the building as now being used by the Bureau of War Risk Insurance, these test results and the examination of the above-mentioned formulas indicate that radical modifications should be made in that system before further Government buildings are so designed. It is demonstrated in the Bureau's report that this method of deducing the allowable working stress on a floor consisting of tile and concrete leads to an erroneous factor of safety.

Laboratory Work on Cement and Concrete

The importance of concrete in building construction was recognized as a war measure, not only on account of its structural advantages, but also on account of its release of less-readily replaceable materials. To meet the greatly increased use of cement and to prevent delay in testing, the Bureau's facilities were enlarged in the Lehigh district by the addition of a chemical laboratory to the physical laboratory and inspector's central office at Northampton, Pa. The construction of a $40 000 000 concrete pier and warehouse at Staten Island for overseas transportation required nearly a million barrels of cement. This cement was shipped in bulk by water from the Hudson district in New York. Very satisfactory laboratory space was obtained at these points, permanent laboratory fixtures installed, and equipment and personnel provided so that the laboratories were functioning in less than a month after the site was selected. This relieved the congested condition in the Washington laboratory, made shipment of samples unnecessary, and materially shortened the time required to report results.

It also seemed desirable to increase the Bureau's testing and investigating facilities on the Pacific coast. After considering the needs of the Army, Navy, and the Emergency Fleet Corporation at San Francisco, Los Angeles, and San Diego, a very convenient laboratory for chemical and physical work was installed in one of the more permanent exposition buildings at San Diego. This

laboratory was especially helpful in the construction of concrete ships, and to both the Army and Navy in their construction of aviation fields on North Island.

The facilities of the laboratory at San Francisco were also increased by enlarging and readjustment of space. The large testing machines of the engineering division of the University of California, at Berkeley, were also made available for the Bureau's use, which was extremely fortunate, since manufacturers of testing machines could not make deliveries in less than a year and all the machines in the country were being worked overtime.

In addition to the routine testing carried on in the Washington laboratory, investigations were made on concrete surface hardeners. From the many commercial products examined, magnesium fluosilicate was found to be the most effective and was recommended and adopted by the concrete-ship section of the Emergency Fleet Corporation for use on the concrete ships.

The light-weight aggregates also required for the concrete ships were examined to determine their composition and resistance to salt water. While this phase of the Bureau's work will be described in detail in another part of this report, it is interesting to state that satisfactory concrete which weighed only 105 pounds per cubic foot was obtained in the laboratory from cellular, hard, burnt clay, while normal concrete weighs from 135 to 140 pounds.

Another investigation which is still in progress was probably caused by trade conditions resulting from the war. In the effort to obtain potash in the cement industry and as this by-product was at times more valuable than the cement, the established procedure was modified to increase the potash yield. As a result, some erratic cements were put on the market.

Some of this cement was passed by the Bureau for important Government work, but after it had been delivered on the job was found to be unsound. This was very disquieting, as it was not believed that the Bureau's method of testing had been faulty, but that the sample tested had not been representative or that satisfactory cement becomes unsatisfactory. To determine these points, runs have been made at the plant where this cement was made, reproducing as far as possible all the conditions under which the cement was produced. No cement has been found to become unsound and apparently the samples originally tested and passed were not representative.

CONCRETE SHIPS

During the war a large portion of the investigational work in reinforced concrete was carried out for the concrete-ship section of the Emergency Fleet Corporation under the direction of a member of the Bureau's scientific staff. Details of this investigational work are given in the following paragraphs. A paper giving a summary of the most important of this work was presented at the annual meeting of the American Concrete Institute, June, 1919.

The Development of a Light, Strong Concrete

In connection with the building of concrete ships a demand at once arose for a concrete having the least possible weight and yet with sufficient strength for this unusually severe work.

This meant that a concrete as light in weight as possible, yet stronger than any used in ordinary building construction, would be needed. The cost was not an important factor, as every pound per cubic foot deducted from the weight of the concrete meant an important saving in the dead-weight of the vessel and a gain in the cargo-carrying capacity.

When it became known that the Government wanted such a material, suggestions and samples were sent to the U. S. Shipping Board from all parts of the country.

It was the function of the Bureau of Standards to test these samples and aid in the development of the ideas and suggestions that were submitted.

Two ways of lightening the concrete were suggested: (1) The use of a light-weight aggregate; (2) the use of a light-weight cement. The use of a light-weight cement, which was usually a mixture or blend of Portland cement and a light-weight adulterant, such as diatomaceous earth, gave a concrete only a few pounds lighter than ordinary concrete and caused a marked reduction in strength and an increase in absorption.

It was by the use of a light-weight aggregate that a satisfactory light and a strong concrete was finally obtained. This was a burnt clay or shale, puffed during burning to about double size, and which is light in weight because it contains many small, closed cavities throughout its mass. It is produced commercially both in a stationary brick kiln and in a rotary cement kiln and crushed to proper size after burning.

Many other light-weight aggregates, particularly volcanic rocks, were submitted and were tested in concrete. In general they were tested in two classes of concrete: Class A, 1 part cement, two-

thirds part of fine aggregate passing a sieve (No. 8) having an opening of 0.093 inches, 1⅓ parts of coarse aggregate smaller than one-fourth inch, but retained on the No. 8 sieve, or a 1:1:1 mix of the same materials; Class B, 1 part cement, 1 part of fine aggregate smaller than one-fourth inch on a No. 8 sieve, and 2 parts of coarse aggregate, one-half to one-fourth inch in size.

It was planned to use Class A concrete in the major portion of the ships, and it was assumed that Class A concrete, which is really 1:2 mortar with twice as many coarse particles as fine, would give a compressive strength of 4000 pounds per square inch in 28 days under working conditions. Because of the small amount of space between reinforcing bars and forms, the maximum size of aggregate was one-fourth inch.

Class B concrete was designed for use in the larger sectioned areas of the ships; it is a 1:3 mix with one-half inch as the maximum size of aggregate.

As a result of these investigations it may be stated that the old idea that an aggregate must be heavy and dense to produce strong concrete or that a heavy and dense aggregate will produce a better concrete than a light one is not true.

For mixtures rich in cement, such as were included in these tests, a concrete stronger than the aggregate it contains can be made. As an example, the average compressive strength of salmon underburned bricks is 1765 pounds per square inch (with a range of 1380 pounds to 2240 pounds), while the 28-day strength of concrete made using these bricks crushed as aggregate was as high as 3800 pounds per square inch in a rich mix.

Based upon these tests, the Shipping Board manufactured and used on a commercial scale a burnt clay or shale aggregate in the concrete ships which it constructed.

A description of this material, its method of manufacture, and tests of concrete made from it and used in the ships may be found in the Engineering News-Record for April 24, 1919 (28, No. 17, p. 802).

Corrosion Tests of Reinforcing Steel

The corrosion tests were made to obtain information relative to the importance of corrosion of the reinforcement in concrete ships and to methods of preventing or mitigating corrosion of the reinforcement. About 20 proprietary coatings, including paints and asphalts, were used as protective coatings, and salt-spray tests were made to determine their effectiveness. Many of the coatings were found to be effective in preventing corrosion, but to have

serious effect in reducing the bond strength of steel when embedded in concrete. (See section on "Protective Coatings.")

Bond Tests

Pull-out tests of specimens, consisting of steel bars coated with the protective coatings previously referred to, were made on about 400 specimens. These tests showed that practically all coatings, even including metallic coatings such as zinc, had a deleterious effect on the bond strength (the resistance to slipping through the concrete) of bars embedded in concrete.

Repeated Reversal of Load on Reinforced-Concrete Beams

An investigation of double-reinforced concrete beams loaded in alternate directions was carried out, using special machines designed for this work by the Bureau. One of these is illustrated in Fig. 9. Four beams were tested to failure, and in all cases failure was by tension in the steel. One beam, which was subjected to 2 000 000 applications of the design load, showed no indication of the approach of failure at the time the test was discontinued. In one beam there was a large amount of slip of a reinforcing bar before failure occurred. Within the limit of these tests there is no indication that the strength of a doubly reinforced-concrete beam (reinforced for bending in opposite directions) is determined by the properties of concrete, if the ordinary requirements of design are met, unless it be that of the bond stress. The abrasion of the concrete at the edges of cracks in reinforced-concrete ships was considered as a possible danger, and the tests were initiated to obtain information on this subject. There is no indication that this is a real danger. Not all the tests originally planned have been completed. The danger of slipping of bars either where they are lapped at the center of the span or where at the end of the beam they do not have anchorage by hooking of the bars is one which should be investigated. This investigation is fully described in Technologic Paper No. 182.

Impact Tests on Concrete Slabs and Built-up Steel Plates

In an effort to secure a basis for comparison of resistance of concrete slabs and steel slabs to impact, tests were made in which the impact was furnished by dropping a 1-ton ball upon the center of the slab. Eight reinforced-concrete slabs and one steel slab, designed to represent conditions on reinforced-concrete ships and steel ships, respectively, were tested. Six of the reinforced-concrete slabs were 6 feet 6 inches by 7 feet in size, and two of them were 10 by 10 feet. The steel slab was 12 by 10 feet 2 inches in size.

FIG. 9.—*Special machines for producing alternating stresses on concrete beams of the type used in concrete ship construction*

These machines cause stresses similar to those which would be produced by waves acting on the completed ship. The number of repetitions of stress necessary to cause failure of the beams is automatically recorded

FIG. 10.—*The nine sizes of dry cells recommended as standard by the Bureau as the result of its investigations*

Before this work was started the military services were using over 40 different sizes of cells, resulting in a great deal of useless expense and trouble

Leakage of Water Through Cracks in Reinforced-Concrete Shell

Early in the investigation of shearing strength of reinforced-concrete beams it was found that cracks were likely to form when shearing stresses were considerably lower than those which it seemed necessary to use in the design of concrete ships; yet it was not known whether these cracks were such as would permit leakage of water through them or not. Tests were made in which hollow beams were loaded in such a way as to cause diagonal tension cracks in the side walls at the same time that the beam was filled with water, which was maintained under pressure varying in head from 15 to 30 feet. These tests indicated that the smallest crack which could be detected—say 0.001 inch or less in width—would permit the passage of enough water to cause a moist surface on the outside around the crack. As the crack width increased the leakage increased rapidly, provided that time was not given for the closing up of cracks by the deposit of sediment of any kind. When the crack was 0.01 inch wide, water spurted clear of the outer surface of the beam. When the beam was allowed to stand overnight with the pressure head and the load maintained, the leakage was decreased markedly. This was probably due to the deposit of a substance which helped to fill up the cracks. Further indication of this was shown by the appearance of efflorescence on the surface of the beam in the neighborhood of the cracks. If the cracks had been very small at the time of their formation and had developed very slowly, it is possible that the silting would have kept up with the opening of the cracks and that leakage would not have occurred. Apparantly this is what happened with some of the concrete ships and barges which are afloat. An inspection made on a concrete ship which had been in the water about a year showed the presence of cracks which were large enough to cause leakage under the conditions to which these test beams were subjected. However, there was no leakage, although the cracks were below the water line, and apparently there had been none. There was efflorescence apparent at cracks on the inside of the hull, indicating that the process of silting had been taking place.

Shear and Compression in Reinforced-Concrete Beams

These tests were begun as a part of the study of reinforced concrete in adapting it to use for the construction of concrete ships. One of the first serious difficulties in the designing of concrete ships was that of getting sufficient strength to prevent cracks forming diagonally in the vertical sides of a ship of practicable

weight. Using the methods ordinarily employed in reinforced-concrete design, a shell thickness of at least 15 inches would have been required instead of the 4 inches used in the 3500-ton cargo ship. Tests of large reinforced-concrete beams were started to make certain that no mistake was being made in using a 4-inch shell. These first tests were made on (1) beams of 4 feet 4 inches deep and 18 feet 6 inches long; (2) one beam 10 feet deep and 22 feet long; and (3) specimen ship frames of full-sized cross section and 20-foot span. The frames were cut off at a point corresponding to the point of inflection, or 4 feet 6 inches above the top of the keel. The tests were made in the 10 000 000-pound testing machine at the Pittsburgh laboratory of the Bureau of Standards.

For the beams the load was applied at the center of the span upon the upper flange. The beams were supported at each end of a steel-plate girder. The beam, 10 feet deep, was first loaded 40 times with 640 000 pounds, which was four times as much as the maximum which the standards of the joint committee on concrete and reinforced concrete would have allowed as its working load. The widest crack at the first application of this load was 0.013 inch, and with 40 repetitions of the load there was no appreciable increase in the widths of the cracks. The beam was then inverted and load was applied in the opposite direction, causing failure at 1 363 000 pounds, or nine times as much as the joint committee standards for reinforced-concrete design would have allowed as a working load.

The ship frames were tested by applying first only a vertical load and adding later a horizontal load at the sides corresponding to the horizontal water pressure on the sides of the ship. It was found that the strength here was about eight times as great as the joint committee recommendations allowed for the working load, also that the shear due to the horizontal forces reduced the stresses set up by the shear due to the vertical forces; in other words, that the horizontal water pressure would reduce the stresses caused by the vertical shearing forces on the frame.

These tests made it possible to design with confidence for shear in reinforced-concrete ships, using working stresses much higher than those which are recognized by the final report of the joint committee. In effect, the joint committee report limits the amount of web reinforcement to about three-fourths of 1 per cent, while these tests show that for deep beams a much larger amount of reinforcement would be effective. Apparently, the main reason for the higher shearing strengths found in these tests is

the larger percentage of web reinforcement which may be used effectively in deep beams where the web bars have much better chance for anchorage than in shallow beams.

After these preliminary tests were completed, a more nearly exhaustive investigation was initiated at Lehigh University, Bethlehem, Pa., for the concrete-ship section of the Emergency Fleet Corporation.

In the economical use of building materials, the importance of using higher shearing stresses in reinforced-concrete beams has been recognized by many. The results of the tests made for the concrete-ship section were so significant in this direction that the Bureau continued the investigation after the program of tests as related to concrete ships was completed. In all, 172 beams have been tested, and the results have been quite fully worked up, giving data for a technologic paper which should be of much importance to the reinforced-concrete industry.

The conclusion from these tests is that not only working stresses in shear may properly be increased, but that they may be increased to such an extent that other features of the design become the controlling features. In order to make use of the high shearing stresses permitted, compressive stresses would be increased beyond all present reasonable values. This led to the making of tests to determine if an increase in compressive stresses was permissible. These tests were only four in number and not sufficient to afford a basis for a general conclusion, but, so far as they go, they indicate that higher working stresses in compression than are now generally recognized could be used with safety. It is important that further tests of this kind be made.

Reinforcement of Concrete Slabs

There has been much uncertainty as to the relative economies of reinforcing slabs with (1) bars in the direction of the span, (2) bars making some angle with the span, and (3) expanded metal. Twenty-six slabs, 4 inches thick, were tested, in each of which one of the three methods of reinforcing described above was used. The results as they stand indicate that the largest amount of steel is required in the case in which the bars are placed diagonally with the span, and that as regards quantity of steel required there is a slight advantage for expanded metal over the use of bars in the direction of the span. However, certain conditions of the tests make it important that more tests be made before this question is considered to be settled.

Length of Lap Required for Reinforcing Bars

Tests were made to determine how great a length of lap is necessary for cases in which the reinforcing bars used are shorter than the span and are applied by lapping them in the center of the span. Four beams were made in this series, and the indications from the test results is that with this size of bar (one-half inch round) a lap of about 50 diameters is required. The concrete used in these beams had a strength of about 5000 pounds per square inch, and it is to be expected that with a leaner concrete a larger lap would be necessary. Some information from tests in which expanded-metal reinforcement was lapped in the same way is available. As to quantity of steel required for the lap, this indicates a slight advantage in favor of expanded metal.

Value of Brackets and Haunches in Flanges

For purposes of architectural effect or for increasing the strength, connections between columns and beams are frequently provided with brackets. This development sometimes takes the form of an arch construction. However, in the design little attempt is usually made to determine how much strength is added by the presence of the haunch, and usually advantage is taken of only a portion of the value of the haunch or bracket. In the design of reinforced-concrete ships the strength value of such brackets is of much importance. To obtain information on this subject, a series of tests was made, including as test specimens eight reinforced-concrete frames having a span of 14 feet, a height of 7 feet, and brackets ranging from no bracket to one so large as to give the appearance of an arch. These tests indicated that the brackets had much more value in strengthening the frames than that for which allowance is usually made in the design. The results are of much importance, since the weight of the frames in a concrete ship can be reduced materially by taking full account of the strength added by the brackets in the frames. If the results are adapted to general design in reinforced concrete, they will have an important bearing on the reinforced-concrete industries where such structures are involved.

Shrinkage of Concrete in Setting as Related to Ship Construction

It is recognized that shrinkage of concrete occurs during setting. In many constructions this is manifested through cracks which appear in the concrete surface, but the laws which govern this shrinkage have not been very thoroughly determined. This subject becomes important in connection with the concrete ship, since,

as pointed out in a previous paragraph, the smallest cracks will permit a slight leakage unless silting prevents it. In one of the barges constructed by the Emergency Fleet Corporation for the Inland Waterways Commission a series of careful measurements was made in the effort to determine why more frequent and larger cracks occurred in this barge than occurred in the others. While the effort was not entirely successful, the measurements did show that there was an elongation and shortening of the barge which corresponded closely to even the slightest rise and fall of temperature. With any rise in temperature the cracks began to close, while with a decrease in temperature the cracks opened. The largest crack present was less than 0.01 inch, and although the barge was not loaded the results of examinations of concrete ships which have been in service indicate that a deposit of silt or efflorescence will prevent leakage through cracks of this size.

ELECTRIC BATTERIES

Development of Chemical Work on Batteries

In connection with the testing of electric batteries for the various branches of the War Department, the chemical work has been carried out for the purpose of checking up the data obtained from the electrical tests and for the purpose of obtaining information which might suggest improvements in certain types of batteries. At the request of the Signal Corps chemical analyses of batteries and materials entering into their construction were made.

This work included tests upon both dry-cell and storage-battery materials.

The chemical work on dry cells has consisted in (1) the chemical examination of the component parts of finished dry cells; (2) the examination of raw materials which enter into the construction of dry cells; and (3) the development and improvement of special types of dry cells.

The chemical examination of the finished dry cell had for its object primarily to determine whether it contained the quantity and quality of materials necessary to give the service expected. In competitive tests of batteries of different brands, the results of chemical analyses of these batteries placed them in the same order of quality as did the results of the electrical tests. The chemical tests have the advantage of greater speed than the electrical tests, which require the battery to be discharged for a period of time. It must be understood that the chemical tests, at the

present stage, indicate only the capacity or output of the dry cell and not its shelf-life qualities. The shelf life of a dry cell depends upon factors which at the present time it is impossible to determine by chemical analysis. Since, however, these factors are dependent upon the physical and chemical properties of materials composing the cell, it seems entirely possible to devise tests which will indicate the shelf characteristics.

When the chemical work upon dry cells was begun, there were no methods of analysis for the examination of dry cells given in the treatises on batteries, and the laboratories of some of the manufacturers hesitated to make known to the Bureau even such chemical information as they possessed on the subject. It was necessary therefore to start at the beginning and devise a routine method of analysis to furnish the information desired. This work consisted not so much in the development of new methods as in the application of the usual analytical methods to this particular problem. As a result a procedure has been developed for the chemical examination of dry cells which seems superior to the methods used by the manufacturers, which now have been made known to the Bureau.

It was found that a determination of only two constituents—ammonium chloride and manganese dioxide—was sufficient to indicate the capacity of the dry cell. The other principal constituents—namely, carbon, zinc chloride, and water—were determined; but it has not yet been possible to draw valid conclusions from the results, except that the content of zinc chloride and water, as well as the starch paste, are some of the factors which determine shelf life. Certain impurities, deleterious to dry cells in the manganese ore, such as copper, antimony, cobalt, nickel, etc., were determined, and in some cases failures of the cells were attributed to these.

In order to obtain data that may suggest methods of analysis for determining whether a dry cell has good shelf life, an investigation has been started upon a large number of cells of a certain brand. This study consists simply in analyzing at intervals of several months cells from this lot, and, at the same time, determining the electrical output of cells from the same lot. By comparing the results of chemical analysis with the results of the electrical tests, it is hoped that the causes of deterioration may be found. When this information is obtained, it should be possible to determine by chemical examination whether a dry cell will have a good shelf life.

The examination of the raw materials entering into the construction of dry cells is a much simpler problem than the examination of the finished dry cell, since the difficulty of analysis increases with the number of constituents present.

The manganese ore situation was critical when the supply of Caucasian ore was cut off by war conditions. This made it necessary for the manufacturers to conserve their supplies of Caucasian ore and experiment upon the use of ore from other sources; namely, Japan, Cuba, Brazil, and domestic sources. The lack of information about the proper use and suitability of these ores for dry-cell manufacture produced an uncertainty in the industry which caused hesitancy on the part of the manufacturers in guaranteeing their product to be equal to that of prewar times. For this reason, complete analyses of manganese ores were requested by the Signal Corps.

In connection with the foreign assembly of batteries by the Signal Corps, some of the raw materials were examined to determine their suitability and uniformity of quality. This work involved no difficulty except in the examination of manganese ores. Incidentally, some of these ores were being purchased by the Signal Corps for French manufacturers, whose methods of manufacture are somewhat different from American practice. The difficulty in the examination of the manganese ores is the determination of impurities, very small amounts of which are so deleterious that in some cases only a few hundredths of 1 per cent of certain metals will cause destruction of the dry cell within a few days.

The analyses conducted by the Bureau included both samples of natural ores of unknown sources and artificially prepared manganese dioxide. The methods for determining the small amounts of impurities in the presence of large amounts of manganese had to be worked up, as no published methods for such determinations were to be found. A method of procedure was devised for determining arsenic, antimony, copper, cobalt, nickel, and iron. In addition to the difficulty of accurately determining these small percentages, it is still more difficult to interpret the results because of the lack of definite information about the limits of impurities permissible. From a chemical analysis alone it is not possible, for instance, to state whether 0.05 per cent of copper will be deleterious, because the deleterious action of the copper depends upon the particular physical or chemical state in which it exists. Neither does the MnO_2 content as determined by chemical analysis give a

reliable indication of the suitability of the ore. In factory practice the question of suitability of the ore is determined by actually making a cell from the material and then observing its electrical characteristics. This kind of a test requires considerable time, since it is necessary to wait several days or even months for results.

It was on account of this inconvenient expenditure of time for making such a test that the largest manufacturer of dry cells requested the Bureau to undertake the study of manganese ores, with the object of devising some quick method for determining the suitability of ores. This company furnished the Bureau with samples of ores, some of which were known to be satisfactory and some unsatisfactory for dry cells. This study was undertaken by the Bureau but has not been completed.

In connection with the tests of the Ba-2 battery for radio sets for the Signal Corps, it was found that the specifications did not require a sufficiently long shelf life for foreign service. As a result, many thousands of these batteries were scrapped before they had opportunity to give any service. In an effort to devise a battery which would have a long shelf life, several types of reserve batteries were tried. These batteries were made up from the same mixture of materials as are used in ordinary dry cells, except that no water was added to the mixture. In the dry state the cell will keep indefinitely, provision being made in the construction of the cell for the addition of water, which is all that is necessary to make the cell active whenever it is desired to use it.

Failures in this type of battery were usually due to leakage of the electrolyte between the cells of the battery, which was due principally to the difficulty in providing satisfactory insulation.

It was suggested that a construction similar to the voltaic pile might be designed to give a voltage and capacity sufficient for the service required. After numerous trials, a simple type of construction was designed which met the requirements. The Signal Corps considered the design of sufficient importance to request that the matter of obtaining a patent be undertaken.

At the suggestion of the Signal Corps a visit was made to the factories of the leading manufacturers to obtain data upon the shelf life of cells (⅝ by 1⅞) used in the Ba-2 batteries, and samples of cells of various ages were obtained for test. Also, results of shelf tests on all cells made during one year by a certain manufacturer were summarized, and showed this make of battery to be superior in shelf characteristics to other brands. On the

basis of the results obtained on this trip, the Bureau recommended the use of this make of cell in Ba–2 batteries, provided that they were shipped unassembled to France to be assembled into batteries when desired.

The chemical work on storage batteries for the War Department was devoted principally to the study of methods of tests and comparison of specifications for sulphuric acid used in storage batteries. The need for this information was emphasized when the Signal Corps requested such data for making specifications to be used by a large number of manufacturers and users of batteries, and it was found that the specified amounts of impurities varied as much as 1000 per cent.

Some of the methods in common use for testing battery acid were found to be unreliable, this being particularly true in the methods for determining the amounts of nitrates and nitrites. Much labor has been spent upon the comparison of methods of testing preliminary to the main problem of determining the limiting amounts of impurities permissible, and eventually of drawing up reasonable specifications for battery acid.

In connection with the comparative testing of truck storage batteries for the construction division of the Army, the electrolytes of the batteries were analyzed. The results of analyses showed that the batteries giving the best electrical performance contained the purest electrolyte, while the batteries giving the poorest electrical performance contained the most impure acid. These chemical tests were, therefore, confirmatory of the quality of the different brands of batteries tested.

In addition to the work upon battery acid some analyses were made upon special storage-battery plates and fillers for dry storage batteries.

At the request of the Signal Corps analyses were made upon a large number of alkaline electrolytes taken from storage batteries supplied by the Edison Co. to determine whether they contained the specified amounts of potassium and lithium hydroxides.

Standardization and Preparation of Specifications for Batteries

Before the United States entered the war, questions relating to dry cells were brought to the attention of this Bureau by several of the military departments. The first problem presented was to find a suitable cell of American manufacture which could be used to replace cells purchased by the British Navy from manufacturers in Scandinavian countries. This and other problems emphasized

the need for the Bureau undertaking a systematic study of battery problems. Information has been secured on the performance and specifications of dry cells from publications on the subject, by consulation with the manufacturers wherever possible and by experiments in the laboratory. The collection of information with regard to storage batteries has been undertaken in a similar way. The information which the Bureau has gathered has been made available to military departments (1) in the form of special reports when these have been asked for; (2) in reports of tests on batteries which have been submitted; (3) in a circular of information about dry cells; (4) by cooperation with the Standardization Committee of the War Department.

The Bureau has prepared and published a circular of information on dry cells (Circular No. 79) which contains a brief historical review of the development of the dry cell and the theory of the reactions which take place in it. The various kinds of construction are described in detail, since this has an important bearing on the utilization of the cells. The two most common types are the so-called "paper-lined" cell and the "bag-type" cell. The paper-lined cell is the one most commonly made in this country, and it is well adapted to some purposes, besides being easily and cheaply manufactured. It does not possess, however, as desirable characteristics as the bag-type cell for many of the uses which resulted from the war. This is because the cells deteriorate when standing on open circuit. If long periods of time must elapse between the manufacture of the cell and its use in a distant field of operation, the deterioration which takes place greatly reduces the service which the cell can render. The bag-type cells of the larger sizes are less subject to this deterioration and are more commonly used in Europe than in this country. However, the small flashlight cells which are made in the United States in very large numbers are nearly all of the bag-type construction, this being necessary since the deterioration of these small cells is more rapid than in the larger sizes.

The circular describes sizes and kinds of cells which are available on the American market and the uses to which they are best adapted. The electrical characteristics are discussed with a view to showing how the best service may be obtained from the cell, an important matter, since it often happens that dry cells are used in such a way that only a small part of the service which they might perform is obtained.

The tests which are commonly made on dry cells have grown up with the industry; many are not considered to be entirely satisfactory, and some are not easily carried out. Nevertheless, these tests are discussed in detail, since in the absence of simpler and more reliable tests, they are the only ones that can give relative information as to the performance of the various brands now on the market.

Specifications covering all of the various sizes and kinds of dry cells in common use have been prepared by the Bureau and incorporated in the circular as an appendix. These specifications were prepared as a possible guide for the various Government departments in the purchase of dry cells, and they have been formally adopted by the War Department.

Before the circular on dry cells was published, the War Department undertook the standardization of electrical supplies in general, and a subcommittee on batteries, consisting of officers representing a number of different bureaus of the War Department and two representatives of the Bureau of Standards, was appointed. When this committee began its work, the question of specifications for dry cells was immediately taken up. The specifications which the Bureau had already prepared served as a basis for the discussion which took place in the committee, with the War Industries Board, and with the War Service Committee of the Manufacturers. Only minor changes in these specifications were made, and an agreement was reached with all the parties concerned. The Standardization Committee then adopted these specifications.

Two important results of these specifications were, first, the limiting of the number of sizes which are considered as standard, and, second, the specification of the minimum service required of the different sizes. In limiting the number of sizes, the Bureau had the cordial cooperation of the manufacturers who had been more or less compelled in the past, for trade reasons, to manufacture a large variety of shapes and sizes for which there was comparatively little use. The number of the large-size cells was cut from 10 to 3, and of the small or flashlight cells from an indefinite number, about 40, to 6. (See Fig. 10.) The Bureau also had the cordial cooperation of the War Industries Board in thus limiting the number of standard sizes, since part of their conservation work was directed toward the elimination of useless sizes. It is probable that the Bureau's recommendation for limiting the number of sizes would have been made mandatory by the War Industries Board

but for the signing of the armistice. It is anticipated, however, that the Bureau's recognition of these as standard sizes will lead the manufacturers to eliminate gradually those which are less desirable.

This subcommittee on batteries also considered the question of storage batteries. The Bureau cooperated by gathering information from various sources about the characteristics and performance of different types of storage batteries. The Bureau also carried out extensive tests on these batteries as described elsewhere. Specifications covering storage batteries were prepared jointly by representatives of the construction division of the War Department and by the Bureau of Standards in consultation with the engineering committee of the Manufacturers' Association. These specifications were formally adopted by the standardization committee.

Reports on Special Subjects

The Bureau has been called on in a number of instances for information dealing with battery problems by different bureaus of the Government departments. Only three of the more important of these will be mentioned here.

A controversy arose between the Food Administration and a large manufacturer of batteries concerning the use of wheat flour in the manufacture of dry cells. This flour is used for making the electrolytic paste which separates the zinc container from the depolarizing mixture in the cloth bag. A few manufacturers in this country have been using cornstarch instead of the wheat flour, but this process of manufacture of the cell is so entirely different from the more common or wheat flour process that a manufacturer using one process could not change to the other without alteration of the methods and machines employed. For this reason the proposal of the Food Administration to prohibit the use of wheat flour in the manufacture of dry cells was a serious one to the industry, and particularly so in the case of the abovementioned company, whose product was largely for the War Department. At the suggestion of this company the Food Administration referred the matter to the Bureau of Standards, and conferences were held with both the manufacturer and the Food Administration. A satisfactory basis of agreement was found, since it is possible to manufacture dry cells with wheat flour which is unfit for human consumption. Accordingly, the Bureau recommended to the Food Administration that the battery maker be

permitted to use such flour, and apparently this recommendation was entirely satisfactory to both parties.

A request was received from the Bureau of Ordnance of the Navy Department for information on silver chloride cells with a view to their use in submarine mines. In addition to reporting on the structure and electrical characteristics of these cells, the Bureau made tests on sample batteries which were submitted by the Navy Department.

In connection with the testing of storage batteries for industrial trucks and tractors, it was requested that additional information be furnished on the relative characteristics of acid and alkaline storage batteries as applied to tractor work. The Bureau gathered information on this subject from various reliable sources, and the report was made as a lecture before the truck and tractor committee of the War Department and other officers whom they invited to be present.

Military Tests of Batteries

About 50 tests on batteries of various kinds have been made for the military departments, many of which have involved an extended series of measurements. The purpose of some of these tests has been to determine the fitness of various kinds and makes of batteries for particular purposes, while in other cases the object was to determine the quality of material submitted by manufacturers. In still other cases the work has taken the form of experimental development of new types and kinds of batteries to meet unusual service conditions. A brief description of some of the more interesting tests is given below.

A test of over six hundred 15-cell batteries of the type Ba-2 has been made for the Signal Corps. These batteries were intended for use in the amplifiers of radio sets such as are used in airplane service, but had not given satisfactory service, due to deterioration when standing idle, as in storage or in transit. This had been so large that many of the batteries had been found unfit for use when wanted. The Bureau was asked to make a study and test of these batteries to find what could be expected of them and what improvements could be made. Nearly 700 of these batteries, representing the product of several manufacturers, have been sent to the Bureau for test. In addition to testing these batteries at the Bureau, measurements were also made on much greater numbers in the military storehouses during June and October of 1918, the results of the latter measurements showing that very large

percentages of the batteries in storage were unfit for service. The deterioration of dry cells is more rapid in the smaller than in the larger sizes, and for this reason it was suggested to the Bureau of Steam Engineering of the Navy Department that similar batteries for Navy use should be made from larger cells. This recommendation was adopted and shortly afterward the Navy bought batteries containing cells of the recommended size, which they designated as CBG-3535. The Signal Corps, however, preferred not to use batteries of a larger size, since they would not fit in the compartments of their apparatus. The Bureau suggested that batteries might be made in such form that water could be added to the individual cells at the time they were required for use, thus making them similar to the so-called "reserve" or "desiccated" cells which are common in the larger sizes. It was also suggested that these batteries might be assembled in France, since in this way those for use abroad could be obtained without the delay which otherwise occurred between the time of manufacture and their utilization. This work was undertaken by the Signal Corps in the latter part of the year.

Tests which the Bureau made showed that, of the batteries manufactured in this country, some were distinctly superior to others, and it was therefore suggested that a large number of individual cells of the best makes, complete but not assembled into batteries, should be shipped abroad so that each cell might be tested individually at the time they were to be assembled. In this way those which were defective might be discarded. Most of the batteries manufactured in this country were assembled without any such tests being made on the individual cells, and the Bureau considers that this is partly the reason for the large number of failures which were experienced. As the failure of any one cell is sufficient to cause the failure of the entire battery, it is apparent that the chances of the battery failing are 15 times as great as that of the failure of any one cell. In a number of cases the Bureau was able to show conclusively that the failure of the battery was of this type.

One result of the Bureau's experiments was to show that a very simple empirical test of these batteries could be made in the military storehouses or in the field, which would give reliable information as to whether they were fit for service. This test consisted in measuring the voltage of the batteries with an ordinary voltmeter and discarding any batteries showing less than 20 volts. This test depends on the fact that the ordinary voltmeter of 100

ohms per volt of the scale draws enough current from the battery to indicate whether the latter is in fit condition, in addition to indicating what may be termed its semiopen circuit voltage.

The batteries tested at the Bureau were discharged under many different conditions. In one of these experiments it was found that when they were discharged at temperatures below 0° C or 32° F the service rendered was very small even though the batteries were in good condition. This is a matter of importance, since the service in airplanes, for which they were intended, may expose them to very low temperatures.

In addition to the electrical tests a careful chemical examination of the contents of some of the batteries was made. The results indicate clearly that those giving the most satisfactory service were the most uniform in their chemical composition and contained sufficient manganese dioxide and other ingredients.

Batteries similar to the above, but designated by the Signal Corps as type Ba–5, have also been tested in large numbers. These batteries are of the so-called "reserve" type; that is to say, the battery is made up dry and is made active by adding water at the time it is required for service. Numerous mechanical difficulties developed in connection with these batteries owing to the difficulty of providing sufficiently large vents for adding water. Since these batteries were assembled dry, there was no means of testing them until such time as the water was added when they were required for use. For this reason, large numbers failed almost immediately after being filled with water because of the leakage of electrolyte from the cells into the battery, causing short circuits. It was found that batteries which did not show this initial defect gave reasonably good service. The results of the Bureau's tests on these batteries indicated that the percentage of failures due to leakage was rather too high to consider them satisfactory.

Another type of battery intended for the same purpose, and designated by the Signal Corps as the type Bb–12, is made up of 12 small storage cells. They were made as an experiment by two different manufacturers and were of the so-called "dry" or non-spillable type, in one case the battery electrolyte being thickened with gelatin. The service which these batteries gave was unsatisfactory, and it also developed that when they were placed in a closed compartment containing other apparatus the metal parts of the latter became corroded. The Bureau's experiments indicated that these batteries should not be used.

The Bureau undertook, at the request of the Signal Corps, a study of the galvanic pile to ascertain its suitability for furnishing the small currents required of the batteries mentioned above. In the course of this investigation a form of disk battery was developed which is rugged and can be made active by the addition of water as in the case of the reserve cells. They are now being made at the Bureau and assembled for further tests. These batteries have certain advantages over those of the Ba–2 and Ba–5 type, although the actual service which they will render is slightly less than the others when the latter are in the best condition. The units of this disk battery are usually small dry cells, but the Bureau has also made experiments on a similar construction, in which the elements were to be those of a storage battery. In the case of the disks assembled as a battery the cells are assembled in a glass tube, so that the battery can be watched during the time it is in use. Such an arrangement reduces the maximum difference of potential between adjacent cells to 1½ volts, a distinct advantage in diminishing leakage trouble. Experiments on this form of battery are being continued.

An unusual test of dry cells intended for use with a trench signal projector was made at the request of the Bureau of Aircraft Production. Its object was to ascertain how long the batteries would operate the signal lamp satisfactorily. In imitation of the service anticipated, the lamp was caused to flash twice in each second with a duration of one-fourth second for each flash, and measurements were made on the batteries until the light given by the lamp was no longer serviceable. On this test various types and sizes of dry cells were used, some of them being ordinary cells, while others were of the bag-type construction.

Competitive tests of various brands of flash-light batteries were made for the Depot Quartermaster, the Field Medical Supply Depot, the General Engineer Depot, and the Ordnance Department, to show the relative merits of the different brands submitted, as a basis for large purchases. The experiments showed conclusively that in the case of a few brands, on which an unusually low price had been quoted, the cells were of very inferior quality. After these tests were completed and contracts awarded, the General Engineer Depot asked the Bureau to test samples of the batteries furnished by the manufacturer, to determine whether they conformed with the samples which he had submitted. A large number of batteries of various kinds were submitted for

test by the Signal Corps, in addition to those which have been previously mentioned.

At the request of the Bureau of Ordnance a long-duration test was conducted on the shelf life of special batteries designed for use in submarine mines. Part of this test consisted in keeping the batteries under temperature conditions comparable to those of sea water with the idea that this Bureau should notify the Navy Department when they might expect failures of the batteries in planted mines. They also requested information and tests on silver chloride batteries, and a number of experiments were made. This cell differs materially from the ordinary dry cell, as the depolarizing agent is chloride of silver instead of manganese dioxide, and the cells are less subject to deterioration on open circuit than the ordinary dry cells. An examination was made for the Navy Department of six small dry cells which had been taken from a German submarine mine.

The extensive use which has been made of the dry battery in the present war has been emphasized by the number of different military organizations which have requested tests by this Bureau and by the number of different kinds of batteries which they have submitted for test. Altogether, more than 1600 dry cells or batteries have been delivered to the Bureau in connection with purely military tests. In many cases these tests have been of a special character because of the use for which the batteries were intended. The results of the Bureau's experiments and tests have been not only to benefit those requesting the information, but in several cases have led to important changes on the part of manufacturers. This is particularly true in one case where a manufacturer has carried out a partial reorganization as a result of the Bureau's work in showing the poor quality of the cells which were being supplied.

The Bureau has carried out a test of large storage batteries such as are used for the propulsion of electric trucks and tractors. These batteries were representative of seven different manufacturers, and they were tested for capacity, efficiency, and ability to maintain their voltage over widely varying conditions. Likewise, some measurements were made at low temperatures, and a number of experiments were carried out to determine the velocity and acceleration of an electric tractor when equipped with different types of batteries. The request for this test came from the chairman of the Committee on Standardization of Electrical Equipment and Supplies.

The results showed that some of these batteries gave a very satisfactory performance in the laboratory. Others, however, failed to equal their rated capacities, and these for the most part gave a relatively poor performance on the other tests to which they were subjected. The batteries may be divided into two main classes: (1) The lead-acid type of storage batteries, including the ordinary flat-plate type of 15 or 17 plates per cell and some similar styles with thinner plates, and the so-called "ironclad" or pencil-plate batteries; and (2) the nickel-iron storage batteries, containing alkaline electrolyte.

Measurements of the ampere-hour capacity of these batteries for continuous and intermittent discharge were made, and their efficiencies were determined at the normal rate of 45 amperes and at 90 amperes discharge. There was no great difference between the various makes of lead-acid batteries, but both the ampere-hour efficiency and the watt-hour efficiency of the alkaline batteries were distinctly lower than in those of the lead type. The watt-hour efficiency of the different types of batteries has an important influence on the cost of charging them. The average voltage of the different batteries at the normal rate of discharge was approximately the same for all the different types tested, the differences being less than 2 per cent, but at the highest rate of discharge—that is, 350 amperes—the average voltage of the alkaline batteries was found to be only 60 per cent of the average for the lead batteries. Measurements on these different types of batteries at low temperatures indicated that the lead-acid batteries gradually decrease in capacity as the temperature of the cell is lowered, but a different phenomenon was observed in the case of the alkaline batteries. It was found that for these a certain critical temperature, dependent on the rate of discharge, exists, below which the battery can give but a very small output.

The experiments made with the electric tractor equipped with the lead-acid batteries and the alkaline batteries consisted in making exact measurements of the velocity and acceleration of the tractor operating under different load conditions. For this purpose a series of 39 electrical contacts was prepared, spaced at definite intervals along the path of the truck and arranged to be broken as the truck passed along. The time at which each contact was broken was recorded on a smoked paper record which also bore a time scale. This latter apparatus was developed by the section of the Bureau devoted to work on sound ranging. From the records obtained the time at which each contact was broken

was determined to within 0.01 second, and from the time observed and the spacing of the contacts it was possible to calculate the time-distance diagram from which the curves of velocity and acceleration were plotted. The results of this test showed that when the truck was running without load or with only a light load, its speed after the attaining of a unifrom velocity was greater when the truck was equipped with the alkaline batteries, but when the load was increased beyond 2 tons a greater velocity was obtained with the lead-acid batteries. This observation confirms the laboratory tests which showed that, at the higher rates of discharge, the alkaline batteries could not maintain as high an average voltage as the lead type, due to their higher internal resistance. It was also found in testing these alkaline batteries that when the tractor was heavily loaded and running up a grade of 3 per cent, the acceleration of the tractor at the end of the run was negative; that is to say, the tractor had attained a maximum velocity which the alkaline batteries were unable to maintain.

A number of other tests of storage batteries have been made, but these will not be described in detail. The Signal Corps submitted to the Bureau some military batteries of French manufacture, which were constructed with celluloid containers. A considerable fire hazard is encountered when celluloid is used, as a bad contact between two cells may ignitc the celluloid. In one case examined the complete destruction of the battery was prevented by an outer container also of celluloid which inclosed the individual cells. This did not burn through before the oxygen within was exhausted and the fire extinguished.

For testing portable storage batteries submitted by the Signal Corps a rack was constructed and installed at the Bureau. The Bureau provided facilities and cooperated in the supervision of this test, but the personnel for carrying it out was provided entirely by the Signal Corps.

An interesting test of small storage batteries was made for the Chemical Warfare Service. These were intended for use with individual smoke precipitators to prevent the clogging of gas masks.

ELECTRIC BLASTING APPARATUS

About June 1, 1918, the Bureau of Standards was requested to undertake an investigation of equipment used by the American Expeditionary Forces in the electrical ignition of explosives. Two branches of the Army were concerned with this apparatus—the Ordnance Department, the officers of which were developing

equipment for firing Livens gas projectors, and the Engineer Corps, which was charged with the problems of demolition.

The Livens gas projectors are designed to be hurled into the enemy's territory from points near the front-line trenches. Short shafts are sunk in the ground and the projector placed therein above a charge of powder. A small primer (or squib), made of a capsule containing fulminate of mercury and guncotton surrounding a fine metal wire, is placed in the mass of powder. This is so connected to external wires that it can be fused by sending through it an electric current of the proper intensity. This fusion ignites the material of the primer, which in turn fires the entire charge under the projector. A similar primer was used by the Engineers to fire charges of dynamite in demolishing bridges and other structures of value to the enemy.

Electric Generators

The apparatus used to generate electric current for this purpose should have at least three characteristics, especially when used for military service. First, it should be reliable; second, it should be portable; and, third, it should have ability to supply a sufficient amount of energy to insure firing the primers connected to it. It is important that the operator shall be absolutely certain that when his generator and circuits are properly arranged he can depend upon them to fire, for most of this work involves life hazard for the men detailed to it.

Closely allied with this is the ability to supply sufficient energy. The complete demolition of a bridge often requires from 30 to 60 separate charges of dynamite, each sometimes containing two primers. The electric generator should then be capable of firing all of these simultaneously, which means that it should generate sufficient voltage to force through all the primers in series a current of the proper intensity.

The necessity for compactness scarcely needs any comment. The conditions under which these generators are used prohibit an elaborate arrangement of permanent apparatus. The source of power should be capable of being carried about by one man with ease.

At the beginning of the war there were available in this country several small generators which partly met the above requirements. They were being built for use in mines and quarries, and were called by the trade name "electric blasting machines." A typical machine of this sort, with the number of primers which it would

FIG. 11.—*The old type of blasting machine used for firing primers when the United States entered the war*

The total number of primers which this machine is capable of firing are piled at its base

FIG. 12.—*The improved blasting machine developed for the use of our overseas forces by the Bureau*

It is interesting to compare the number of primers which this machine will fire (shown at its base) with those shown at the base of the old machine in Fig. 11. The machine likewise proved to be much more reliable, and a great deal easier to manufacture

FIG. 13.—*Set of gage blocks constructed at the Bureau*

Prior to the war all such blocks were made in Europe. As these are used as reference standards in munitions plants, large numbers were required during the war. The Bureau aided by producing many sets in its own shops

FIG. 14.—*Electric lamps for daylight transmission of messages*

The type of lamp used, means for causing flashing signals, and other phases of the problem were studied

ordinarily fire, is shown in Fig. 11. They were small, portable, series-wound, two-pole, direct-current generators, in appearance somewhat like the early Edison dynamos. The armatures were of the Siemens type, and both armature and field were of solid iron. A long rack with a handle is meshed with a pinion on the shaft of the generator. In operation the external circuit of primers was connected in parallel with a switch, short-circuiting the generator. As the rack was pressed down, current flowed through the generator and short-circuiting switch. At the end of the stroke, this switch was opened by the rack, thereby making available a comparatively high voltage to force current through the circuit of primers.

These machines were portable and were probably reliable enough for the purposes for which they had been used. However, soon after the American Army began using them, it became clear that their capacity was very limited, and that even with only a few primers connected to their circuits, they often failed to function. Upon examination of the constructional details, some members of the Bureau's staff recognized that they were precisely similar to generators designed for the same purpose more than 25 years ago. In view of the great development in the electrical field during that time, the Bureau was asked to undertake an investigation to determine whether a generator could be designed of approximately the same size and weight, but of greater reliability and capacity.

It was apparent that with solid-iron construction the output of these generators was much below that of machines of similar size constructed along modern lines. Accordingly, the experimental work was begun by securing several standard direct-current motors, such as are used for driving electric fans, and arranging them to be driven as generators. After testing the capacities of several such machines and making a number of changes in the electrical design (such as size of wire and number of turns on armature and field), it appeared that a machine could be built with considerably greater capacity and with practically no increase in weight. Moreover, iron castings and stampings, which were being used in large quantities in electrical factories in the manufacture of small motors were suitable for this purpose. As the Army had immediate need for these generators, this was a decided advantage.

Some trouble developed in these experimental machines in the form of armature breakdowns. The new generators, wound with

fine wire, generated voltages which were too high for the insulation of the wire. Using heavier insulation, however, at the expense of a smaller number of turns, solved this difficulty without seriously detracting from the capacity.

These results were communicated to the General Engineer Depot about one month after the investigation began. Meanwhile, urgent messages had been received from the commander of the American Expeditionary Forces in France, telling of numerous failures of the blasting machines and setting forth the necessity for a more reliable source of current. With the results of these tests, the General Engineer Depot took up with two of the large manufacturers of electrical apparatus the question of adapting stock material to the building of a new generator. By October 1, 1918, the details had all been worked out, contracts had been let (with these two companies) for 10 000 generators, and the machines were already in production. Since the unreliable blasting machines in use constituted a real life hazard, arrangements were made by which large orders for them already placed were canceled.

As a result of this work there was made available for the Army a portable generator which was capable of supplying sufficient energy to fire 100 blasting primers connected in series without danger of failure. Its weight was no greater than that of the early blasting machine, which was rated at 20 primers and accomplished this only occasionally. The improved machine developed by the Bureau is shown in Fig. 12. The large number of primers which it will fire should be contrasted with Fig. 11.

Incidentally, the cost of the new machine was only about 90 per cent of that of the earlier one, due to the fact that its construction was similar to that of other machines already being manufactured in large quantities, so that while far greater reliability and capacity were secured, several hundred thousands of dollars were saved to the Army in the machines then contracted for.

Primers

In order to determine the electrical output required of the blasting generators, a study was made of the current required to fire the primers and of the time between the application of the current and the explosion of the primer. This latter information is of importance in cases where a number of caps are connected in series, as it is essential that the slowest cap be heated to the ignition point before the explosion of the fastest cap interrupts the circuit.

The tests were made on both the Ordnance Department's gas-defense squibs, in which the body of the primer is filled with black powder, and on the caps used by the Engineer Corps, which contain a charge of the high explosive known as "tetryl." A fine copper wire was tied around each cap to be tested in such a way as to be broken by the explosion of the cap. A weak electric current passing through this copper wire was recorded on an oscillograph, as was also the actual firing current which passed through the fuse wire in the interior of the primer. From the photographic record obtained the instants at which (1) the firing circuit was closed, (2) the fuse wire was melted by the current, and (3) the outer wire was broken by the explosion of the cap, could all be determined to 0.0001 second.

Three different arrangements of circuit were tried and found to give concordant results at each of the different values of firing currents used.

The conclusions drawn from the results are as follows:

1. Both types of cap tested have substantially the same current-time characteristics.

2. A current of at least 0.4 ampere is required to insure certain firing of a single cap.

3. At small currents, the explosion occurs before the resistance wire is fused by the current. In the case of the tetryl caps this explosion invariably breaks the bridge wire, but in the case of the black-powder squibs the wire sometimes survives the explosion undamaged and is later fused by the current. This can not be depended upon, however, to maintain the circuit when several squibs are connected in series.

4. At the large currents (above 3 amperes) the wire is fused by the current before the explosion occurs.

5. The measurements at the large currents indicate a fairly constant time interval of 0.004 second between the heating of the wire to the ignition point and the explosion of the charge.

6. At currents of 2 amperes and below, the maximum variation in firing time among different primers is greater than this 0.004 second, and consequently there is some danger that the circuit may be interrupted by the explosion of the quicker caps before the slower ones reach ignition temperature.

7. In the tests with three caps in series, all three caps fired in all trials at 1 ampere or above. It appeared from these tests that the small current (only 0.9 ampere) which was delivered by the old-style machines would explain the reason for their unsatisfactory

service, and that a machine of considerably greater current capacity was required. The new design of generator chosen by the Engineer Corps delivers 1.5 amperes at 300 volts when connected to a circuit of 100 caps in series, and the current is correspondingly greater when fewer caps are used. Under these conditions the caps are fired in about 0.01 second with practical certainty.

ELECTRIC TRACTORS AND TRUCKS

This investigation was planned and executed by members of the staff of the Bureau of Standards, assisted by representatives of the construction division, Engineer Corps, and Ordnance Department of the Army.

The object of the work was to obtain complete information relative to the mechanical and electrical details of construction and operation of electric tractors and trucks for the use of the Government departments when purchasing and using such equipment.

The tests were conducted at the Union Station, Washington, D. C. The electrical and mechanical inspections were made by engineers of the War Department, and during the inspection of each vehicle representatives of the makers were present. The scope of the work included the following: Performance tests to determine operating characteristics; electrical inspection of wiring, motors, and control apparatus; and mechanical inspection of framework, gearing, brakes, and safety features.

Object of Tests

The object of the performance test was to determine the comparative operating characteristics of the tractors and trucks. The following data were obtained:

(1) Energy consumption in watt hours per ton-mile; (2) load-carrying capacity in ton-miles per hour; (3) operating speeds; (4) power taken from the battery.

In general, each of the above characteristics was determined for two (or more) loads under two conditions: (1) On an approximately level surface of smooth concrete; (2) on an asphalt-block surface having a grade of 6.5 per cent.

Method of Testing

Each run was made over a measured course. The truck or tractor was brought up to speed before reaching the starting point. The current taken from the battery, the voltage at the battery terminals, and the time to traverse the course were observed, each

by a separate observer. Readings were taken at intervals of 10 to 20 seconds, depending on the speed of the vehicle. Each vehicle was operated by a representative of the maker.

In the case of the tractors the load consisted of trailers on which were placed bags of sand, the loaded trailers having been weighed on a platform scale. In the case of the trucks the platforms were loaded to their rated capacity, and where additional load was required it was obtained by coupling trailers to the truck.

On account of the limited time allotted to the work, only two loads, in general, were applied to each vehicle. For the tractors the loads used were approximately 4000 and 25 000 pounds on the nearly level surface and 4000 and 8800 pounds on the 6.5 per cent grade. For the trucks the corresponding figures were 4000 and 12 000 on the level and 4000 on the 6.5 per cent grade. In a few cases intermediate loads were used, and this would have been done for all vehicles if time had been available.

In all, 13 tractors and 14 trucks were tested, representing 12 manufacturers. In accordance with an agreement with the makers, the results were reported in full only to Government departments for their confidential use. Each maker was supplied with all the results, but only the data on his own products were identified, the remaining data being marked with arbitrary numbers.

Results of Tests

The results were reported in the form of curve sheets. They included transportation capacity in ton-miles per hour and the energy consumption in watt hours per ton-mile, both as functions of the load, the speed, and the power taken from the battery, these being likewise expressed as functions of the load.

Limitations Shown by Tests

Three of the tractors stalled when part way up the 6.5 per cent grade with a load of 8800 pounds. One of them was tried at an intermediate load—namely, 5000 pounds—but its transportation capacity fell off noticeably as compared with the 4000-pound load. The fact that the tractor was probably much over-loaded when pulling 5000 pounds is indicated by the steep rise in the corresponding curve of watt hours per ton-mile. Another one of the trucks required an excessive value of watt hours per ton-mile at the 4000-pound load.

Using the results of these tests, a committee of the War Department on which the Bureau of Standards was represented prepared

specifications for standardized trucks and tractors for warehouse and other Government use. In drawing these specifications, special attention was given to the dimensions of battery compartments, in order to adapt them for use with the different types of battery required for various service conditions.

As an important by-product, it is believed that this test, which was the first thorough comparative test of its kind, had an important influence on the improvement of trucks and tractors as supplied later for commercial purposes.

ELECTRICAL INDUCTANCE METHOD FOR LOCATION OF METAL BODIES

At the beginning of the war a number of devices, which depended upon the effect of iron on the inductance of a coil brought into the neighborhood of the iron, were submitted to the Bureau for criticism. In order to properly criticise these devices, it was necessary to make experiments and accumulate data so that the Bureau could readily determine by an examination of the drawings whether the proposed devices would operate. Accordingly, a number of coils were constructed and experiments performed to determine the effect of a mass of iron on the inductance of the coils. Incidentally, it was found that a nonmagnetic metal had nearly as great an effect as a magnetic one on account of the eddy currents which were set up in the metallic mass.

Several different coils were constructed. These differed both in shape and in the number of turns of wire. The largest constructed had a diameter of 1.5 m. There were four coils of this size, each having a winding of 125 turns of No. 18 wire. They were wound in pairs, each pair being on a frame. The distance between the inside edges of the two coils was 1 cm. Other coils of various sizes were used in the course of the investigation.

Two different methods of detecting the change in inductance were employed. In the first, the two coils of a pair were connected in series so that their magnetic fields aided each other. The coils were then connected in an Anderson bridge balanced with a frequency of approximately 1000 cycles per second. When a piece of metal was brought into the neighborhood of the coils, it would change the inductance of the coils and cause an unbalancing of the bridge which would be detected by the current through the telephone.

In the second method, a coil of one pair was connected in series with a coil of another pair. Through these an alternating cur-

rent was sent. The other two coils were connected so that the induced electromotive forces were in opposite directions. Normally the induced electromotive forces were equal, so that no current flowed through a telephone receiver in the circuit. However, if one coil was brought near a mass of metal the induced electromotive forces were no longer equal, causing a flow of current through the telephone. To make this sensitive on alternating current, a frequency of 500 to 1000 cycles was required.

This method may also be used on direct current employing a galvanometer instead of a telephone. In this case, however, it is necessary that the coils be so arranged that the variations in the earth's magnetic field do not produce a current through the galvanometer.

The two methods were approximately of the same sensitiveness when used with alternating current. If the coils near the mass of metal are moving, then the direct-current method becomes more sensitive than the alternating-current one. Of course, there is no effect whatsoever when the coils near the mass of metal are stationary. The results given below apply only to the use of alternating current.

By using one pair of the large coils described above in the Anderson-bridge method and applying 175 volts at 500 cycles to the bridge, a sheet of iron 120 cm square was detected. Sheets of zinc and copper were tried and their presence was detected quite as well as pieces of iron. In fact, a thin sheet of copper containing 6000 sq. cm could be detected at the same distance as a sheet of iron containing 11 000 sq. cm.

In using the second method indicated above and applying 500 cycles and 0.5 ampere alternating current to the coils, the same sensitiveness was obtained as indicated above for the Anderson-bridge method. However, when used with direct current, which is interrupted twice per second, the same piece of iron was detected at a distance of 4 m.

By means of a small coil connected to a telephone the field of one of the coils was explored. The field could be readily detected at a distance of 30 m from the coils.

The theory would indicate that for a given piece of metal the effect on inductance would vary approximately inversely as the 4th power of the distance from the coils. The experiments indicate that the theory agrees with practice. It is also to be expected that the distance at which iron can be detected will depend on the area of the iron.

GAGES, PRECISION

Testing of Munitions Gages

The entrance of the United States into the World War resulted in the manufacturing of guns, ammunition, and other ordnance material on a strictly interchangeable basis on a scale never before attempted in this country. By interchangeable manufacture is meant the practice of manufacturing in different factories and different parts of the country the various parts entering into a completed mechanism, and then assembling these parts at some central point. One of the prime requisites of such a manufacturing practice is an adequate gaging system. Only such a system will insure that the various parts or components, wherever made, will, when brought to the point of assembly, go together and function properly.

It was early realized that in order to put an adequate gaging system into effect, it would be necessary for all master gages to be tested by some central organization provided with suitable equipment and trained personnel. The Bureau of Standards was selected as the proper and logical organization to perform this important function, and the gage section was organized and equipped for that purpose.

At the gage laboratory in Washington and the branch laboratories in New York; Bridgeport, Conn.; and Cleveland, Ohio, more than 60 000 munitions gages were tested.

Manufacture of Precision-Gage Blocks

In the manufacture and inspection of accurate machine products, a series of standards of comparison is absolutely essential. The need for such standards is usually met by the use of precision-gage blocks. Prior to the war, Sweden was the source of the only satisfactory precision-gage blocks, and during the progress of the war the demand for these blocks far exceeded the supply, and as a result prices became excessive and an adequate supply was not available at any price.

In 1917, there was brought to the Bureau of Standards an idea of a method by which the inventor believed that precision-gage blocks could be manufactured commercially that would be equal in every respect to the Swedish blocks.

The Bureau was of the opinion that the idea was susceptible of successful development and, after presentation to the War Department, an allotment of funds was made by that department for the purpose. Apparatus was designed and either purchased or built as speedily as possible, and the idea developed and put into opera-

tion. After a certain experimental period satisfactory blocks were turned out, and in the course of the following months 50 complete sets of blocks ranging from 0.05 inch to 4 inches were completed. Fig. 13 shows a set of gage blocks made by the Bureau.

Salvage of Obsolete Gages

Of the thousands of gages used by the Ordnance Department of the Army in the inspection of munitions, large numbers were continually becoming obsolete by reason of changes in design or because they had been worn out in use. Of these obsolete and worn-out gages a considerable number could be so rebuilt as to again become useful. A gage shop was established at the Bureau of Standards, and nearly a thousand gages were salvaged and about 500 new gages built for the Ordnance Department.

School of Instruction in Gage Work

For inspecting the immense quantities of munitions produced during the period of the war, a large corps of trained inspectors was necessary. The available supply of properly trained men being entirely inadequate, it was necessary to train many new men for this work. As an aid in this training work, a school of instruction was established at the Bureau, and in this school 50 persons were given courses of from one to two weeks of intensive training in the work of gage inspection. Among those to whom this training was furnished may be mentioned representatives from 13 district ordnance offices, 2 navy yards, 2 arsenals, the Motor Transport Corps, and 2 large manufacturers.

Publications on Gage Work

Much of the useful information and experience gained by the gage section has been collected in the form of communications and distributed to those in position to use it most advantageously. A list of these communications will be supplied on request to those interested.

ILLUMINATING ENGINEERING

Acetylene Generators for Field Service

For some time the Bureau of Standards was asked to make tests of acetylene generators by four branches of the War Department. In all, 9 reports on the subject have been issued, aggregating about 85 pages, exclusive of performance curve sheets, etc. The requests have come from the General Engineer Depot, the Signal Corps, the Field Medical Supply Depot and the Military Intelligence Service of the General Staff.

A test for the General Engineer Depot was made on acetylene generators designed for isolated or field construction work, etc. The purpose of the test was the selection of the best generator for the use of the Expeditionary Forces of the United States. A supplementary report dealt with smaller generators intended for use with small burners for the interior illumination of dugouts, barracks, etc.

Another test was performed for the science and research division of the Signal Corps (later the Bureau of Aircraft Production). For this test two types of generators were submitted by one manufacturer. The generators were to be used for supplying gas at low pressure for use in photographic work in portable laboratories.

Still other work, carried out for the Field Medical Supply Depot, was to determine the most satisfactory types of generators for use in supplying gas for low-pressure lights and instrument sterilization stoves in field hospitals.

The various generators tested were divided into four classes as regards the methods of bringing the water and carbide into contact to cause the generation of the gas. They were as follows:

1. Recessional Type, Water in Excess.—In this type the fuel is supported in suitable racks inside a gas bell open at the bottom. When the gas cock is opened, the water rises in the gas bell until it comes into contact with the fuel. Gas is then generated, increasing the pressure inside the bell and forcing the water down out of contact with the fuel until the pressure drops sufficiently to again raise the water to the fuel level. If the amount of gas generated exceeds the surplus storage space in the gas bell, overgeneration occurs.

2. Recessional Plus Flooded-Compartment Type.—In this type the fuel is contained in trays or compartments without drainage, they being in turn contained in water-tight buckets. When the water rises to a certain level, it is sprayed through holes in the side of the bucket onto the fuel. Unless this type is carefully designed to prevent the admission of an excessive amount of water, large fluctuations of gas pressure and excessive overgeneration will occur.

3. Carbide to Water, Water in Excess.—Only one generator of this type was tested. A clockwork attachment was designed to drop small grains of carbide into water when the pressure fell below a certain value.

4. Water to Carbide, Carbide in Excess.—A few of the small generators, for indoor use, were of this type. The water is

placed in a tank over the carbide container, and is admitted drop by drop through a needle valve.

In order to determine the suitability and relative merits of the various generators for the particular service required, very extensive laboratory tests were carried out. Some of the main features investigated were as follows: (1) mechanical features—ruggedness, weight, design, etc.; (2) simplicity and safety of operation; (3) gas generation characteristics—regularity, pressure fluctuation, amount per pound of fuel, cost, etc.; (4) light distribution with reflectors supplied; and (5) illumination characteristics—candlepower, fluctuation, drift with time, total light output, efficiency, etc.; and (6) effect of low temperature on operation.

The ususal method of making a test to determine the total light output, gas yield, etc., was as follows: A number of generators were given full charges and operated continuously until exhausted. A portable photometer was set up so that the candlepower normal to the bare flame of any one of the flares could be measured. Some or all of the burners were connected to the generators through gas meters, so that the gas yield could be measured. In a number of cases recording pressure gages were connected to record the gas pressure in the generators. Candlepower measurements were made at regular intervals of about 10 or 15 minutes throughout the life of a charge. The total light output, expressed in candle hours, was obtained by taking the product of the average candlepower and the time of burning.

Other tests were made to determine the reliability of the generators at low temperatures. For this purpose several generators were charged and put outdoors when the temperature was about 12° to 15° F. Only one make of generator was free from trouble, due to the low temperatures. In all cases where failure occurred by reason of the low temperature it was brought about by collection of frost in some part of the gas-supply system.

The Bureau's tests for the General Engineer Depot resulted in a recommendation for the purchase of a certain make and size of generator. For satisfactory operation under all conditions, another make was found to be superior to all the other generators tested, but it required a special fuel costing 50 per cent more than commercial carbide, and yielding only about 80 per cent as much gas for the equal weight of fuel.

For photographic enlargements, reproductions, etc., in the field, photographic laboratories were installed in motor lorries. In some of these acetylene generators were used. The Signal Corps,

science and research division, submitted two types of generators manufactured by the same firm for this type of service, with a request for tests. One of those, known as the "Aviation" type, was understood to be of English origin. It was a complex apparatus and was not found to be at all satisfactory. The second type was a special generator combining two gas bells and carbide racks in one water tank. The two were connected in parallel so that either could be used alone, thus making it possible to remove and recharge one while the other was in use. As originally submitted, this generator had no provision for pressure reduction or regulation. Since the generator was to be used for photographic work, it was evidently very necessary to have a constant gas pressure at the burner. The Bureau suggested the use of a certain type of pressure regulator which had been tested and found to give excellent service, but for some reason this suggestion was not adopted. The generator was revised several times in accordance with the Bureau's criticisms, and finally a satisfactory product was obtained. The pressure regulation in the final type of generator was not as good as that obtained with the regulators recommended, but was probably sufficient for all practical purposes.

Generators were tested and inspected which were to be used to supply gas for lights and for stoves used to heat water for sterilization of instruments for field medical hospitals. The tests performed were not very extensive, as previous work enabled the Bureau to select the proper generator without much trouble.

Incandescent Electric Lamps

Fully 95 per cent of the inspections and tests of incandescent electric lamps made during the war were for the Military and Naval Establishments of the Government. For the fiscal year 1918 the enormous total of approximately 10 000 000 lamps was reached on these orders. When the factories reached their full war output, three inspectors were kept in the field, and it was found necessary also to considerably abridge the usual inspection procedure to handle the requisite quantity per day. Even then, the inspection facilities at the factories were inadequate to permit the immediate inspection of all lamps ordered, so that the emergency called for immediate shipment of many lamps, which were, however, usually guaranteed to be of as good quality as the inspected lamps.

During the fiscal year 1919, up to the time of the armistice about 2 000 000 lamps were ordered.

Life tests were operated to the full capacity of the Bureau, and as a result of these tests the manufacturers of tungsten lamps maintained an allowable adjustment of rated efficiencies such that the average quality of the lamps supplied was kept up to the specified standard.

Protective Fence Lighting

In September, 1918, the War Department, through the construction division of the Engineering Department, requested the Bureau of Standards to conduct competitive tests of flood-lighting units, in order that they might standardize their practice in the use of flood lights for protective lighting of ordnance depots, etc.

The Curtis Bay Ordnance Depot, near Baltimore, Md., was said to be typical of the areas to be guarded. Its area was several square miles, and the fence line was irregular. The fence was composed of heavy woven wire and was about 6 feet high, surmounted by three strands of barbed wire, making the total height approximately 7 feet. The fence passed through fairly rough country, with weeds, bushes, and trees outside it. The flood-lights, equipped with semicylindrical hoods about 2 feet long, were attached to posts placed just inside the fence and were so supported that they were about 20 inches outside the fence, with the axis of the beam approximately parallel to the fence. The path of the guard was from 10 to 100 feet inside the fence, parallel to it, and was of a fixed length.

The general question of protective lighting received a great deal of attention during the war period. Several articles dealing with this subject were published during that time, some of which are as follows: Electrical World, June 15, 1918, page 1268; General Electric Review, October, 1917, page 816; Journal of Electricity, December 15, 1917, page 540; War Department Document No. 800, "Protective Lighting;" Bulletin No. 30 of the Engineering Department, National Lamp Works, Cleveland, Ohio.

In none of the above articles had a satisfactory system been outlined for the service conditions that existed in the ordnance depots. A satisfactory system for these conditions had to possess the following features:

1. No Light on or Inside of the Fence.—If any light falls on the fence, it is very difficult to see through, as the fence presents the appearance of an illuminated grating. If any light falls well within the fence, it illuminates the patrol route of the guard, which makes him visible to anyone outside the fence.

2. Bright Foreground.—The foreground outside the fence should be lighted to an intensity sufficiently high to reveal the approach of any person at a distance of 50 to 75 feet, either by silhouette or by direct illumination.

3. Penetration.—The light outside the fence should come from such a direction or directions that there will be no serious shadows due to uneven ground or bushes. Hence, in order to give the proper penetration, there should be an appreciable angle between the light beam and the ground.

4. Uniformity of Illumination.—The illumination should be of such uniformity as to form no dark spaces which would interfere with the vision of the guard.

5. Spacing.—Units should be spaced sufficiently close so that long, dark spaces would not be created by the failure of one light. Short spacing is also necessary to give good lighting in foggy or stormy weather.

6. Glare.—Protective lighting units should create a dazzling glare in the eyes of anyone outside the fence and a minimum glare to the guard. The ideal conditions would be to have a blinding glare to the prowler and at the same time have the lighting units totally dark to anyone inside the fence. Since it is impossible to have the protected area dark on moonlight nights, the most effective way to decrease the vision of the prowler is by the use of glaring lights projected in his direction.

Nearly all of the units submitted were equipped with "spill rings" or "baffles" over half of the front glass. These spill rings were designed to let through all the light projected approximately parallel to the axis of the floodlight, but to deflect or absorb all light which would normally be projected to one side of the axis.

In order to test the effectiveness of the various flood lights submitted, a tower was built beside the fence around the Bureau. This fence is of woven wire, similar to that described above. The flood lights were mounted on this tower and the beams projected beside the fence. Observations were made from both inside and outside the fence to determine how closely the various units fulfilled the above conditions. A number of such tests were made, the final conclusion being that none of the units was satisfactory for this purpose. It is evident that if the flood-light projects any light within the fence it would be necessary to entirely obliterate one-half of the beam or else deflect it to the outside, if the lighting is to be satisfactory. This would mean that the beam must change from a maximum value to zero within 1° or 2°. It is apparently

impossible to accomplish this. Even a small amount of light inside the fence causes a glare in the eyes of the guard if he has to face it at any time, and the amount of light necessary to reveal his presence was found to be surprisingly low. Where the fence is not straight and the area to be protected is very large, it is practically impossible for guarding to be successfully accomplished by a guard making a complete circuit of the fence. Hence, when he is traveling back and forth over a definite route, he must at some time face one or more units, and, as has been observed, these may seriously interfere with his vision, even at distances as great as half a mile.

The principal faults of flood lights for this type of protective lighting when used in a manner similar to that at Curtis Bay, may be summarized as follows:

1. LIGHT ON AND INSIDE THE FENCE.—Even the best units tested were open to this objection.

2. NONUNIFORM LIGHT ALONG FENCE.

3. DARK SPACES FOR 25 TO 50 FEET ON EITHER SIDE OF EACH FLOOD LIGHT.

4. LACK OF DOWNWARD PENETRATION.—Since the light strikes the ground almost at grazing incidence for a good part of the way, it will not penetrate hollows at appreciable distances from a unit, and weeds or bushes may make long shadows, thus creating hiding places for prowlers.

5. LACK OF DISTANCE PENETRATION IN BAD WEATHER.—If the weather is foggy or rainy, the flood-light beam may not penetrate sufficiently to be effective over distances greater than 200 feet, thus leaving long spaces insufficiently illuminated.

6. GLARE IN THE EYES OF THE GUARD.—At Curtis Bay this condition was found to exist even at distances of one-half mile or more.

7. LACK OF GLARE OPPOSING THE PROWLER.—Since any person approaching the fence receives the light from one side, it has practically no glaring light in his eyes.

8. SERIOUS EFFECTS OF FAILURE OF ONE UNIT.—If one lamp burns out, a long space is left dark, this space being approximately the spacing distance.

Consideration of the disadvantages of flood-lighting units led to the conclusion that much more satisfactory results could be obtained by the use of local units with short spacing; these units to be of such a nature as to project the maximum intensity in a direction out from the fence, and give fairly uniform illumination

along the fence. Several types of reflectors were obtained for these tests.

The Bureau's tests and demonstrations apparently show that for protective fence lighting a system composed of elliptical reflectors, equipped with 100-candlepower Mazda C street series lamps, or 100-watt Mazda C multiple lamps, mounted about 10 feet high, spaced about 40 to 50 feet, and inclined outward about 45° from the vertical, would be quite satisfactory and far superior to any other system investigated, and would apparently be better than any other units now on the market.

The reflectors recommended are enameled metal reflectors with an elliptical cross section, and are inclined outward when the lamp axis is vertical. When the lamp axis is inclined outward about 45°, the units being suspended about 1 to 2 feet outside the fence, practically all the required conditions as outlined above are fulfilled. The reflectors are cheap and durable, and are easily cleaned.

Small units with short spacing are superior to large units with longer spacing, for the following reasons:

1. More uniform illumination along the fence.
2. Greater glare in the eyes of the person outside the fence.
3. Shorter dark space if one lamp fails.
4. Lower wattage lamps are less likely to be exploded by rain or snow than larger wattage lamps.

In order to prevent darkness along a long stretch of fence in case the circuit is broken, it is advisable to have two separate circuits, series or multiple, with alternate lamps on the different circuits. Under these conditions, a single dark space will not exceed 50 feet in case one circuit fails.

This test was made to determine the best units for lighting fences of the type above described, but apparently it would be equally good for solid fences; in that case, however, it would be desirable to set the units at such an angle that some light would be thrown on the inside of the fence.

Rockets and Illuminating Shells

In modern warfare rockets and illuminating shells are extensively used for lighting up the battle field, revealing enemy movements, making light barrages to obstruct and defeat enemy attacks, indicate the trajectory of projectiles, etc. The types and uses have been described by A. Bergman in the Transactions of the Illuminating Engineering Society (**13**, No. 4, p. 219; 1918).

Previous to the fall of 1917 rockets and shells for these purposes were bought without specifications as to their performance, as regards illuminating value and smoke produced. Since their function is to furnish a high illumination for a short time, and since some of them are suspended from parachutes while burning, it is very important that there shall be as little smoke produced as possible. Immense quantities of these materials were being purchased by the War Department, and there was available no quantitative information about their performance. Four things had to be done: (1) To make measurements on samples obtained from different sources in order to find out what might reasonably be expected of each type of light; (2) to try to improve the performance by modifying the composition and construction; (3) to draw up specifications stating the performance required; and (4) to test samples of material purchased under the specifications. In the fall of 1917 the Trench Warfare Section of the Ordnance Department of the Army requested the Bureau to assist them in this work by making candlepower tests of materials then available and of samples submitted by manufacturers, and to develop methods of determining the amount of smoke produced.

The determination of the candlepower of illuminating shells, etc., is fairly simple. For this purpose, the shells were burned upright, and the candlepower was measured as many times as possible during the period of burning, a Sharp-Millar portable photometer being used for the purpose. In order to get an arbitrary measurement of the amount of smoke produced, they were burned under a hood. The smoke was passed through a vertical cylindrical chamber about 15 inches in diameter and 30 inches high, an exhaust fan being used to stimulate the circulation of the smoke. Two small holes were made in opposite sides of the chamber, at its center. A lamp was placed outside the chamber, opposite one hole, and a photometer was placed at the other hole. Photometer readings were taken when the cylinder was clear of smoke and when smoke was passing through the cylinder. The ratio of the photometer reading with and without smoke gave a value for the light transmission through the smoke under the particular conditions of the test. This enabled the Bureau to obtain *relative* values for different samples, but at no time was it claimed that the conditions were exactly definable or reproducible.

Measurements of candlepower and smoke transmission, as defined above, were made for a large number of samples of shells and

rockets, and the methods were found to be sufficiently satisfactory to make it desirable to refine them and build new equipment. Accordingly, plans for such equipment were drawn up for the Ordnance Department, and a laboratory was equipped for the tests at the American University, Washington, D. C.

In order to tie up the results at the new laboratory with those obtained under the test conditions at the Bureau, samples from a single lot were tested at both laboratories. Fortunately, it was found that smoke transmission tests conducted in the laboratory built according to the plans drawn up here were in practically exact agreement with the smoke tests made under purely arbitrary conditions at the Bureau of Standards.

In the latter part of 1917 the member of the Bureau's staff who had been connected with the tests was given a commission and took charge of the testing at the new laboratory. Since the new laboratory was then prepared to make its own tests, the Bureau's apparatus was dismantled, after making the check measurements referred to above.

Signaling Lamps for Daylight Transmission of Messages

On numerous occasions from September, 1918, to February, 1919, the Bureau was requested to make tests of various lamps and signaling devices for the science and research division of the Bureau of Aircraft Production. The purposes of the tests were (1) to determine the light-distribution characteristics of regular and special types of signaling devices; (2) determination of the intensities necessary for perception of light signals over various distances in daylight; (3) tests of the effect of partially silvering the bulbs used in various units. For the last-named work the lamps were silvered in the laboratory. One of the signaling equipments tested is shown in Fig. 14.

The various devices and lamps tested were used for several types of service, among which may be mentioned the following: (1) Daylight signaling over land, such as that from one trench to another; (2) signaling between airplanes; (3) night signals from an airplane to the ground, indicating that illumination of the landing field is desired.

Three of the units tested may be described as follows: The first is known as the Evans "gyrolite." It usually consists of a small metal reflector and a type C lamp. The lamp is first silvered all over and copperplated, then the silver is removed from the bulb in a band about 1 centimeter wide, so that all the light given off

by the lamp is redirected by the reflector. A special adaptation of the Evans "gyrolite" was used as a signaling unit. A shutter operated by the trigger at the top of the handle furnished the means for flashing the signal. The second type of apparatus is the type EE-10 trench signal unit. Hydrogen-filled lamps with special types of filaments are used in it. The gas is used to produce rapid cooling of the filament, so that flashing signals can be sent by means of an exterior sending key. The cooling is very rapid, and distinct flashes can be sent faster than the eye can interpret them. The Aldis signal lamp, the third type of device, is somewhat similar to the trench-signal unit, but produces flashing signals by tilting the reflector rather than by covering or extinguishing the light.

In September, 1918, the trench-signal unit was mounted on the roof of the electrical building of the Bureau and directed toward an observer stationed about 2 miles away. The sky was slightly overcast. Flashing signals were sent and were acknowledged when received. This test apparently indicated that the minimum intensity visible at that distance to the naked eye was about 1000 candlepower.

In October a signaling test was carried out over a 3-mile range. For this purpose two 1000-watt lamps were used without reflectors. The day was quite dark, the illumination on a horizontal plane being only 500 foot-candles, but the atmosphere over the range was clear. The results showed that intensities below 500 candlepower were invisible at all times, and that an intensity of 1000 or greater would be necessary for certainty of signaling under those conditions.

In the case of lamps to be used for signaling from airplanes to the ground at night, they should be visible over a fairly wide area and should employ an extensive type of distribution.

In order to determine the degree of improvement in the beam intensity and spread which might be obtained with the trench-signal unit EE-10 by partially silvering the lamp bulb, a large number of tests were made. In each case the bulbs were wholly silvered, then silver was removed until all the light which would normally be incident on the reflector was unaffected, while that which would normally fall outside the zone of the reflector was redirected onto it.

Since it is very difficult to direct the axis of the beam toward the point receiving the signals, it is desirable to have a fairly high intensity over a solid angle of 5° or more. It was found that a

ribbon filament gave the best results in this respect. The use of a ribbon-filament lamp in the Evans gyrolite unit achieves the object desired, namely, a fairly uniform distribution through a wide angle.

The Aldis lamp, an English design, uses a special type C lamp of about 25 watts. It has two parallel coil filaments and is operated with the axis of the lamp at right angles to the axis of the reflector, the axis of the reflector being in the plane of the filament coils. The result is an enlarged image of the filament on a screen placed in the beam. Silvering one-half of the bulb results in an increased efficiency, but a comparison with the type EE-10 unit shows the latter to be superior as regards light distribution and efficiency.

INKS AND INK POWDERS

The Bureau of Standards was called upon to do considerable investigation and inspection work on inks for the various offices of the War and Navy Departments. Although much work had been done along this line during the past 10 years for the various civil branches of the Government, many new manufacturers had started up and new products placed upon the market, thereby requiring considerable testing work to determine the merits of this material. For convenience, this discussion will be divided as follows: (1) Ink and ink powder, (2) indelible ink.

Liquid Inks and Ink Powders

Writing ink is a solution or fine suspension of some colored substance in water which will leave a permanent mark upon paper after drying. It is judged by its permanence, durability, and writing qualities. By permanence is meant the resistance which the writing will show to the agents of time, such as light, moisture, and moderate heat. The durability is judged by the freedom from the formation of scum, sediment, and mold. The writing quality is a factor that must also be taken into consideration, inasmuch as some fluids, in spite of excellent durability and permanence, are unsuited for pen work because of improper consistency.

Ordinary writing ink consists essentially of an aqueous solution of iron gallotannate, although Prussian blue, chrome-logwood, copper-logwood, finely divided carbon (India ink), and dye solutions are sometimes used. The various types of fluids were compared with one another in regard to the properties above mentioned and for most ordinary work the iron gallotannate was found to be

the most satisfactory. This type of ink had already been adopted as official by the Government several years previously.

For overseas shipments it seemed desirable to use ink in powder form, if possible, and to dissolve it in water as required. Such a system would greatly reduce shipping space, eliminate breakage, and prove very convenient in the field, where small amounts of ink could be made up at one time. The idea of preparing ink in the form of a powder or tablet was not a new one, as many concerns had been making this material for some time. However, most of these powders were essentially nothing but organic dyes which would dissolve in water to form a colored liquid. The writing produced by such a solution was found to be very fugitive to light and water, and could not be relied upon to produce a permanent record. It was natural, therefore, to try to produce the gallotannate (which was known to be satisfactory) in the powder form. A few manufacturers had done this, but the product was in many respects inferior. The amount of insoluble matter was very high, in some cases equal to 50 per cent of the weight of the powder, Furthermore, the ink did not keep well. In some instances it formed such a thick deposit in less than a week as to render it unfit for use. This will be better understood when it is stated that the gallotannate of iron ink which is purchased in the liquid form contains hydrochloric acid, which is necessary to keep the iron in solution. The hydrochloric acid, which is a gas readily soluble in water, can of course not be produced in the form of a powder. Experiments were carried out using various solid organic acids in place of the hydrochloric. Most of these were found to be unsuitable in that they did not prevent precipitation. Oxalic acid, however, was found to suit the purpose very well and seemed to possess no other disadvantage than that of retarding slightly the rate of blackening of the record.

Indelible Inks

A considerable quantity of indelible ink was required by the various military organizations for labeling garments, blankets, bales, etc. Although this did not require very much investigational work, it was necessary to try a great many of the brands which were upon the market in order to determine their suitability. The composition of these inks varied widely and included solutions of dyes in oils, aniline, and cresol; silver salts; combinations of metallic salts with logwood; suspensions of carbon; and mixtures of copper salts with aniline and some oxidizing agent de-

signed for the production of aniline black upon the fiber. The commission from the French Government reported that they had been using suspensions of lampblack in various vegetable oils, especially peanut oil, for marking uniforms. The West Point laundry had been using a mixture of unsulphonated nigrosine with cresol, which was very successful upon certain fabrics. It was necessary to subject these various materials to practical tests. With the cooperation of the Quartermaster Corps, fabrics were marked with the different inks and carried through the process of laundering. The results obtained were at first very misleading, inasmuch as inks of the same type varied so greatly among themselves as to indelibility. In general, the copper-aniline combinations were found to be very permanent, although it was difficult to produce legible marks with these upon the fabric. Some of the cresol dye mixtures were excellent and would withstand 10 or 15 laundry operations, whereas others were so poor as to be almost eliminated by a single washing. This was at first difficult of explanation, but it was finally concluded that improper dye had been used in the inferior grades. The carbon suspensions, although showing great resistance when soaked in laboratory reagents, were largely rubbed out after a few laundry operations, and the silver inks, although much more expensive, were found to be inferior to the cresol-dye mixtures.

INVISIBLE SIGNALING

Ultra-Violet Position Marks and Ultra-Violet Signaling

Several months before the entry of the United States into the war the Bureau of Standards was requested to advise the Navy as to the selection and specification of a lamp to be used as a stern light, so designed that it would be visible to other ships of the same squadron at 1000 yards (914 m.) astern while not visible at greater distances and not easily picked up by enemy ships.

This request suggested the possibility of screening the source with a filter transparent to ultra-violet, while opaque to the visible, and observing it with a fluorescent detector. Experiments made at the Bureau, February to May, 1917, showed in general the feasibility of this idea; and a letter to this effect was delivered to the Navy Department, June 1, 1917. A detailed technical report was made to the above Department March 6, 1919. Most of the following information is taken from this report, and has also been published in the Physical Review (August and September, 1919).

The experiments were made under the following conditions:

1. SOURCES.—A right-angled carbon arc with current up to 25 amperes and a vertical iron arc with current up to 15 amperes were used. (A mercury arc would perhaps be more favorable than either of these, but was not used because of the a priori conclusion that such a lamp would not be rugged enough for actual service at sea.) No condensing, collimating, or directing mirrors or lenses were used in these trials, although they were recommended for use in service.

2. SCREENS.—Corning glass G–55–A–62, the suitability of which was known for this purpose from tests made in another connection in 1916, and similar glasses made by the Corning Glass Works at the Bureau's request; aqueous solution of nickel sulphate; aqueous solution of p-nitrosodimethylaniline. The wave lengths actually used were in a narrow band centered at about 340–350 μ.

3. RANGE.—Experiments were made in an open range of about 654 m. Rotating sectors were employed to give effect of greater distance. To facilitate the experiments, the sending and receiving stations were in direct telephonic communication.

4. RECEIVER.—The receiver consisted of a short-focus quartz lens forming an image on the fluorescent screen, which was observed by a low-power positive ocular from the opposite side. The observer's eyes were completely shaded by a close-fitting shade, and a thin piece of "purple-ultra" glass (Corning G–55–A–62) was inserted between the objective and the screen. This cuts out extraneous illumination, showing the fluorescent image on a dark background, and is essential to sensitiveness.

5. EXTERNAL CONDITIONS.—All tests were made at night, but under various conditions of light from sky, moon, etc.

The conclusions may be stated as follows:

1. GENERAL CONCLUSIONS.—Working on the above range and with the apparatus mentioned, clearly visible fluorescent images have been observed when the source was nearly or quite invisible to the unaided eye, and the fluorescent image still remained visible when a 4 per cent rotating sectored disk was interposed before the source. However, the following qualifications of this general conclusion must be noted.

It is very difficult to reach any definite conclusions as to the absolute invisibility of such a source to the unaided eye. The

circumstances of the visibility or quasi visibility of the source with filters used in these experiments were as follows:

Even with the best ultra-violet filters, the source was always visible when near it. At the receiving station, when the source was nearly invisible, it could never be focused as a blue or violet point source by the unaided eye, although the same source with a red filter could easily be seen as a red-point source. However, when carefully looked for, an indefinite blue-gray haze, covering a large area of sky, could be seen. This phenomenon is apparently due to fluorescence of the eye media rather than to true visibility of the light transmitted by the ultra-violet filter. The personal equation in the visibility of this blue haze is considerable; it may be invisible to some and quite visible to others. This visibility is a function of age, the source of light being more easily seen by a younger than an older observer. This is due to the senile yellowing of the crystalline lens. Its appearance in the sky is of such an elusive nature that its presence can only be determined by the method of right and wrong answers. The darkness or lack of darkness of the night, of course, affect this visibility to the unaided eye, while not affecting the detector as it was here used. The advantage of this detector over the unaided eye is thus greatest on moonlight nights or with other lights in the neighborhood of the sending station.

The source may, of course, be found and sharply focused by "night glasses" when it is invisible to the unaided eye. However, the fluorescent image may be seen in the detector when the source can not be seen using this same optical system simply as a telescope (fluorescent screen removed).

2. Special Conclusions.—(*a*) An absolutely dark (or invisible in perfectly dark surroundings) ultra-violet source for practical signaling through the earth's atmosphere is not possible, because the source is disclosed by the fluorescence of the eye itself, although the appearance is very vague and ill defined.

(*b*) As position and identification lights designed to be inconspicuous (if not quite invisible) and capable of having their visibility increased to one provided with the fluorescent detector, the ultra-violet screened sources may be recommended as worthy of trial in practice.

(*c*) The method could be used very efficiently at night and the source be made entirely invisible to the unaided eye (probably also to ordinary telescopic examination) if the sending station were

"camouflaged" by bright yellowish lights (carbon filament lamps of arcs screened with "no-glare" glass) placed close to it. The glare from such sources would obliterate the faint blue haze. It seems probable that this procedure would be quite practicable in certain military and naval circumstances.

Regular lighthouses along our coast might send ultra-violet signals which could be picked up by our own ships and never be suspected by any one not equipped with the fluorescent detector.

(*d*) Although we have made no trials by daylight, it would appear that day conditions might be more favorable than night for obtaining the desired result.

(*e*) The best practical signaling apparatus is apparently the iron arc with the Corning glasses and nickel sulphate. The p-nitrosodimethylaniline is not necessary. Silver films have been tried as ultra-violet screens without practical success. The uranyl sulphate was the most sensitive detector tried by the Bureau.

Signaling by Invisible Radiations

In connection with the development of radiometric instruments for secret signaling by means of invisible radiations (whether ultra-violet or infra-red rays), an investigation was made of the photo-electric properties of various substances. The object in view was to find a substance which is expecially sensitive to infra-red radiations. The results were published in Scientific Paper No. 322.

One substance (molybdenite, MoS_2) was found suitable for signaling purposes and was given a thorough investigation as to the effects of temperature, light intensity, humidity, etc., upon its photo-electrical sensitivity. The applications and actual tests of the efficiency of this substance in a thermal radiodynamic signaling device are described elsewhere in this report.

In view of the numerous inquiries received as to the applicability of a bolometer for secret signaling, for detecting the presence of hot objects (for example, the smokestack of a battleship) in a fog, etc., experiments were made in increasing the efficiency of the bolometer.

It is evident that for military purposes the auxiliary apparatus must be robust, so that the use of a sensitive galvanometer is precluded. Hence the bolometer was used in connection with a telephone and an audion amplifier, simply as receiver of thermal radiations. Thus the response of a bolometer was increased by amplifying the electric current which would ordinarily pass

through the galvanometer by passing it through an audion amplifier. In the present experiments the receiver consisted simply of a thin blackened strip of platinum or gold leaf and a storage battery, which were connected to the primary circuit of a suitable transformer. The secondary winding of this transformer was connected to the grid circuit of a three-stage audion amplifier. A telephone receiver was connected in the usual manner to the amplifier.

The source of radiation was an acetylene flame. The receiver was exposed to this flame through a rotating sectored disk having 15 openings. This combination formed a radiophone.

When a sensitive platinum-bolometer receiver was used as a radiophone, the sound produced in the telephone was not very audible. This is, no doubt, attributable to the great heat capacity of the material, which made the rapid changes in resistance, and hence in electric current, of insufficient magnitude to affect the telephone receiver. Fig. 15 shows a field outfit for signaling of this sort.

Using a lightly smoked strip (6 by 2.5 mm) of gold leaf, the ends of which were clamped between thin (0.02 mm) strips of tin, the sound produced in the telephone receiver was as loud as was observed in a photophone made of selenium. This device was mounted in a glass bulb which could be evacuated. As was to be expected, there was no marked difference in the intensity of the sound produced when operated in air and in a vacuum.

In the gold-leaf radiophone, as used, the limit of audibility was attained for a light (radiant power) intensity of 4.8×10^{-6} watts. Using a larger receiver and amplifier and a larger current (which was 0.2 ampere in the present tests) through the receiver, the sensitivity could be greatly increased.

The results obtained indicated that this bolometric receiver device forms a feasible means of secret communication by means of infra-red rays, which can not be detected by the enemy.

From laboratory tests and from data on the energy radiation by a powerful searchlight, it was computed that the range of communication would be 5 miles or perhaps even 15 to 20 miles, depending upon the intensity of the source of radiation and the complexity of the auxiliary receiving apparatus.

Some of the data obtained in these experiments were published in Scientific Paper No. 319.

FIG. 15.—*Field outfit used in signaling by infra-red rays*

This system is the most secret of all means of conveying messages and has been developed to a practical point. It is impossible for the enemy to detect and intercept such messages

FIG. 16.—*Machine for testing the wearing quality of sole leather*

Samples of leather are secured to the rim of the wheel, which is rotated by a small electric motor. This wheel conveys motion, through the leather samples, to a horizontal disk made of an abrasive substance. A brake retards the motion of this disk. Dust is removed by the small vacuum blower. Thus the resistance to wear of each of the samples is determined

Thermal-Radiophonic Devices for Secret Signaling

In secret signaling—the secret transmission of intelligence by means of invisible thermal radiations—radiometry attained its greatest triumphs and its most far-reaching applications.

It is a method of signaling par excellence which, unlike electric-wave signaling, can be directed, which practically can not be detected, and which can be operated without interference.

In the sense that no methods are known for detecting its use (unless one were in direct line of sight), it is a two-edged sword, and it is a moot question whether or not it should be developed further.

The submarine can be combated with depth bombs. Radiotelegraphy and telephony can be detected and interfered with, but the device for the secret transmission of intelligence by means of invisible thermal radiations, while still in its infancy, stands unique as capable of being operated without disclosing its position.

Several writers (Rühmer in Germany and Miessner in the United States) have written books discussing secret signaling devices. Selenium was practically the only substance which was known at that time (1913) to be photo-electrically sensitive and which was discussed as a means of signaling.

The Bureau of Standards became interested in this subject in 1915, but no extensive researches were begun until early in 1917, when a search was made for a substance which should have a marked electric sensitivity for infra-red rays.

The unusually high photo-electric sensitivity, as well as the quickness of response of molybdenite to infra-red rays, renders this substance far superior to selenium as a radiophonic signaling device.

Data have already been given on the thermal-radiation sensitivity of a radiophone in which the (nonselective) receiver consisted of a strip of gold leaf which was smoked on one side. This receiver was connected in series with a battery and the low-voltage side of a small transformer. The high-voltage side of the transformer was connected to the input side of a three-stage audion amplifier of French construction. A Baldwin telephone was used as a receiver of the audible signal. A pulsating electric current was produced by rotating a sectored disk placed in front of the gold leaf so as to interrupt the incident radiations. The heat capacity being small, the variation in temperature, and hence the resistance of and current through the strip, caused by the

intermittent exposure to radiation were of sufficient magnitude to cause the telephone receiver to emit a fairly loud sound. In this radiophone, using a gold-leaf receiver, the limit of audibility was attained for a radiant power intensity of 4.8×10^{-8} watt. The receiver was small, and it was evident that by using a larger receiver the sensitivity could be increased at least four times, or to a limit of 1×10^{-8} watt.

Most of the present radiophonic experiments were made on molybdenite sample No. 1, though good results were obtained with samples Nos. 8, 9, and 12.

The radiophonic tests, using molybdenite as a receiver, differed from those just described employing gold leaf in that no auxiliary transformer was used. The crystal MoS_2 and a battery of dry cells, giving 40 to 60 volts, were connected directly to the input terminals of a French three-stage amplifier. A concave silver-on-glass mirror, 16 cm in diameter and of 50 cm focal length, was used to concentrate the radiations upon the molybdenite receiver. For a field outfit the mirror, sectored disk (operated on a 6-volt battery), and molybdenite receiver were mounted upon a camera tripod.

The radiation sensitivity of molybdenite sample No. 1 was compared with the gold-leaf receiver by exposing it directly to a standard of radiation, using minimum audibility as a criterion for making the comparison. The results showed that molybdenite (sample No. 1) was 160 to 200 times as sensitive as the gold-leaf radiophone.

An interesting test was made of the radiation sensitivity of the field outfit, using the full moon as a source of radiation. A thermopile having the same receiving surface as the molybdenite was used in place of the latter to measure the lunar radiation in absolute value. The molybdenite receiver was covered with colored glasses which absorbed all the visible rays, but which had a high transmission for infra-red rays. Using a single absorption glass, the effect of the transmitted lunar radiations caused a rather loud sound in the telephone. Using two absorption glasses, the sound was still easily detected, so that signals could have been recognized. Under these conditions the energy value of these infra-red lunar radiations was 3×10^{-7} gram-calories per second.

It is, of course, understood that the radiation sensitivity (as determined by ordinary radiation standards) is too low, owing to the fact that much of the incident energy is of wave lengths which do not affect these selective receivers.

A practical test of the field outfit was made, the source of radiation being a 300-candlepower tungsten lamp in a 28-cm searchlight reflector at a distance of 3 miles. The signal stations were the roof of the Bureau's electrical building and the clock tower of the United States Soldiers' Home, respectively. The intervening space was partly occupied by city houses and streets, with attendant dust, etc. The signals transmitted by the aforementioned absorption glasses were loud and easily detected, in spite of a high wind and other disturbances.

Using an automobile headlight consisting of a 20-candlepower tungsten lamp in a 15-cm metal reflector, the signal through the absorption glass was not always heard, showing that this was about the limit of audibility. When this field outfit was sighted upon a street lamp (tungsten filament in a clear bulb, 80 candlepower) at a distance of one-half mile, a clear audible note was heard in the telephone when no absorption glass intervened; but the signal was uncertain when using only infra-red rays.

It is of interest to note that, when using the sectored disk, the molybdenite is exposed to radiation for only about $\frac{1}{500}$ of a second. Nevertheless, in this short interval of time, the electrical conductivity undergoes a change sufficient to produce the effects just described. Hence it may be useful for lecture-room demonstration. Good results may be obtained by simply joining the molybdenite receiver in series with a telephone and a battery of dry cells of from 40 to 80 volts. However, for a really successful demonstration it is desirable to connect the crystal and a battery of dry cells of 30 to 60 volts directly to the input terminals of an amplifier. Using a rotating sectored disk before the molybdenite receiver upon which is concentrated the light of an acetylene flame, the telephone emits a musical note of sufficient loudness to be audible in a remote part of the building.

The method of producing a pulsating current in the telephone by interrupting the light which is incident upon the molybdenite by interposing a rotating sectored wheel is inefficient in view of the fact that (1) only one-half of the incident light is utilized and (2) the exposure time is only about 1/500 of a second, which is not sufficient to permit a great change in the photo-electrical conductivity. A signaling system which can utilize longer exposure of the receiver to the incident light will produce a greater change in the electrical conductivity.

When using the sectored-wheel radiophone, the signal is recognized by the musical note emitted by the telephone receiver.

the loudness of which is determined by the intensity of the incident radiations. The signal could be recognized also by a change in pitch of the sound in the telephone receiver, provided apparatus can be devised to function by changing the pitch of the sound. This change in pitch was frequently observed in the French amplifier used in these experiments, but it was found to be inefficient (insensitive) and not reproducible. However, such a method is feasible. It is based upon the observation of T. W. Case that an audion bulb can be made to transmit a pulsating current. A change in current in the grid, or input, circuit causes a change in frequency of the pulsating current, and hence a change in pitch of the sound produced in the telephone receiver. The time of exposure of the signal light can be made quite long, so as to utilize the full change in conductivity of the crystal receiver.

This method of signaling seemed so attractive that an attempt was made to obtain a test of its efficiency as compared with the sectored-disk radiophone, using, in both devices, molybdenite for the receiver of the thermal radiations which were used in transmitting the signal.

Being unable to obtain the requisite apparatus and working solely upon the report that a suitably evacuated audion bulb can be made to function so as to change the pitch of the sound emitted by the telephone, the following apparatus was devised. An audion amplifier bulb, consisting of a grid, plate, and heating filament, was attached to an oil pump and evacuated to the pressure of mercury, which was found to produce the desired result. The wiring connection used was practically the De Forest audion connections with the grid potential positive. A resistance of 5 to 10 megohms is inserted in view of the fact that molybdenite has a comparatively low resistance, whereas it was found that the circuit must contain a high resistance in order to cause the audion bulb to function properly. The result of this test showed that owing to this high resistance, which was in series with the single receiver of molybdenite, but which did not function photo-electrically when exposed to light, the method of signaling by change in pitch was not so sensitive as the rotating-sectored disk radiophone. Using several molybdenite receivers joined in series so as to obtain the required high resistance when exposed to light, the sensitivity of this device was improved. As already mentioned, it is proposed to make artificial sensitive material.

A photo-electric cell of the gas-ionic type—for example, the potassium hydride photo-electric cell—is well adapted for use

with this change-in-pitch method of signaling. The high resistance is used as ballast to the photo-electric cell. This combination was found to be the most sensitive of the radiophonic type of receivers yet tested. The applied voltage can be adjusted so that the telephone receiver emits a sound only when the photo-electric cell is exposed to light.

Very instructive experiments can be performed with such a device. For example, the rate of charge and discharge can be adjusted so that the sound in the telephone is a series of clicks which increase in rapidity with increase in intensity of the exciting light. It is a simple task in glass blowing to arrange two electrodes and a heating strip (of platinum) to produce ionization.

INVISIBLE WRITING, MEANS FOR THE DETECTION OF

Early in the war it was suspected with more or less plausibility that enemy agents were using so-called "invisible inks" in their communications. The secret-service agents of the Government had intercepted and held on suspicion vast quantities of correspondence, and the Bureau of Standards was asked for advice as to methods of examining this for the suspected invisible inscriptions, which, if existent, could doubtless be developed and read by suitable means. Development and supervision of chemical tests was assumed by other agencies, and this Bureau undertook only the matter of optical and photographic tests. Special apparatus was designed and constructed at the Bureau and used by the offices of the Naval and Military Intelligence. The purpose of this apparatus was to provide convenient and rapid means for the routine examination of a great number of pieces. The methods for regular routine examination were the following: (1) Examination in intense light at grazing incidence; (2) examination of regular reflection; (3) examination by transmitted light; (4) examination in extreme violet and ultra-violet light; (5) examination by ultra-violet photography.

The first three tests mentioned above involved essentially nothing more than specific control of the direction of illumination and the line of sight in the examination of the paper. It is a matter of common observation that faint marks, erasures, indentations, etc., on a sheet of paper can be seen much better at certain angles than at others. The apparatus for tests (1) and (2) merely provides convenient and comfortable means for the critical examination under two specific conditions, both of which greatly accentuate the appearance of irregularities in the paper surface. For

test (3) the paper was laid on a ground glass illuminated from below. No special apparatus had to be constructed, as an Edison mimeoscope served this purpose very well.

Methods (4) and (5) are somewhat further removed from ordinary experience, and so require more explanation.

Method (4) depends upon fluorescence; that is, the property which many substances possess of emitting light when excited by ultra-violet rays which themselves do not cause vision.

Inscriptions made with such substances, dissolved and used as inks, may be quite invisible in ordinary light under any kind of illumination, but show up in bright characters on the darker background of the paper when excited by ultra-violet rays. Paper itself, in common with many materials, is fluorescent in varying degree. If the ink is composed of a substance less fluorescent than the paper, or if the solvent dissolves the surface glaze, the writing will show dark on a light background. Inscriptions written with pure water may be detected in this manner on some kinds of paper.

The test is performed by allowing ultra-violet rays to fall on the paper in a dark room. The ultra-violet is obtained from a Cooper-Hewitt glass mercury lamp screened by a glass which absorbs nearly all of the light from this lamp, while it transmits very freely the ultra-violet and a small amount of violet light.

Method (5) depends upon the fact that some substances may be so nearly the color of white paper as to produce little or no contrast when inscribed on it, while they may differ from it sufficiently in their absorption for ultra-violet as to give noticeable contrast in an ultra-violet photograph. For this purpose ultra-violet rays of wave length considerably shorter than used in the fluorescence test were employed. The quartz-mercury arc and the iron arc are suitable sources for such rays. The blue and violet light and the longer wave length ultra-violet are absorbed by an aqueous solution of nickel sulphate and gaseous chlorine in quartz cells. Since these rays are absorbed by glass, the lenses used must be made of quartz, fluorite, or other material which will transmit them.

Five illustrated technical reports on this subject were issued to the Office of Naval Intelligence during the war. Information on this subject was also given to the division of Military Intelligence. An exhibit of the apparatus used was included in the American Physical Society exhibit at the Bureau, April 25 to 26, 1919.

The methods developed are also of use generally in the critical examination of paper and documents. Last April the Bureau was able to decipher the name and address on a military registration card sufficiently well to establish certain identification of the bearer after the card had been immersed in sea water with the dead body of the drowned registrant so long that it was quite illegible to ordinary observation and the body itself was completely unrecognizable.

LEATHER

The demands caused by the war resulted in a considerable shortage of leather for certain lines of work, and for this reason the study of methods for conserving this material and the development of possible substitutes assumed great importance. The work of the Bureau on this subject was largely composed of routine tests, but at the same time a number of complete investigations were carried out.

Investigation of Sole Leathers

During the early part of 1917 the Bureau was requested to assist in developing a suitable specification for sole leather to be used by the War Department, the object in view being along the lines outlined in the above paragraph. Radically different opinions were held by competent authorities as to just what limit should be accepted for certain of the ingredients found in the many brands and tannages of commercial sole leather. Honest differences of opinion were expressed regarding the effects of added glucose and salts on the wearing quality of the leather.

In cooperation with the National Association of Tanners and with the War Department investigations were started in an effort to determine the effect of these two substances on the wearing quality of sole leather. Four typical tannages were selected for the test, one a long-time tannage with a minimum loading of epsom salts and glucose, one a tannage produced by drumming extract into a half-tanned leather, one produced by loading a half-tanned leather with glucose, and the fourth a medium-tanned leather with a moderate amount of loading. The various leathers were placed on shoes worn by soldiers at Camp Meade, Md., and the wear data were obtained in terms of a day's wear per unit of thickness and per unit of weight. Each type of leather filled with glucose and salts was tested against two types of unfilled leather and vice versa. Each pair of shoes used in tests was soled with two types of leather, one sole of filled and one of unfilled leather. In this manner,

actual wearing tests were made with 500 pairs of shoes, and during the test the soles were inspected weekly by representatives of the Bureau. The data obtained showed that the tannages tested were not materially different in wearing qualities and the leathers tanned to the belting stage and then filled gave about 8 per cent more wear per unit of thickness, and the one stuffed with glucose the best per unit of weight. The analysis of the worn soles showed that almost all of the glucose had leached out of the leather during wear.

Besides the actual service tests on sole leather above outlined a special machine was designed (Fig. 16) for determining the comparative durability of samples of different leathers.

There was found to be a wide variation in the wearing qualities of leather from different portions of the hide. The portions over the kidney showed the best wear, and the wear of the other parts of the bend dropped off so that the leather from the belly edge of the bend gave an average of 73 per cent of the wear obtained from leather about 8 inches from the backbone edge of the bend. That from the extreme shoulder end near the backbone edge also seemed to be inferior in wearing quality. It is thus evident that it is very necessary to specify from what portion of the bend soles shall be cut if the best service is to be obtained. Complete data have been obtained as to the relative waterproofness of the different tannages and the leather from the different locations of the bend. These data showed that the more open and spongy portions of the hide absorbed more water than the more compact portions, although there were several exceptions to this general rule. Considerable water-soluble material was leached out during the immersion in water, and a correction was applied accordingly. The apparent water absorption is always considerably less than the actual absorption, because of the loss of soluble material, and the correction must also be made when the test pieces are immersed for more than an hour. In an immersion of not longer than an hour the amount of material leached out does not appreciably affect the results for water absorption, while in the 24-hour test as much as 11 per cent of water-soluble material was leached out of the leather. This result was found in the case of a leather containing about 9 per cent of glucose. The loss in the other tannages was considerably less, but amounted to 6 or 7 per cent, making a considerable correction, as the total absorption amounts to but 40 per cent.

The complete data obtained from the above tests have been published as a technologic paper of the Bureau, and added details

of the work may be obtained therefrom. The success of this work was largely due to the hearty cooperation of the National Association of Tanners, the American Leather Research Laboratory, and the military authorities at Camp Meade, Md.

Another test showed that a leather tanned to the belting stage and containing 8 per cent of grease will outwear the same leather fully tanned and containing less grease. This test was made on double backs, one side of each back being taken out of the layers at 90 days and finished with a heavy oiling, while the other was left in the layers for 70 days more and finished with the regular oiling with about 2 per cent grease. This method of test eliminates any difference in the quality of the hides and makes a given amount of the data more reliable than where different hides are used. The full tanned leather contained an average of 23.7 per cent water-soluble material and 1.9 per cent grease, while the light tanned leather contained only 13.9 per cent water-soluble material and 9.1 per cent grease.

Composition Soles

As mentioned previously, at the time the United States entered the war the European countries had already used a vast quantity of leather for military purposes; therefore it was apparent that the greatly increased consumption which would be brought about through the participation of the United States in the conflict would result in an acute shortage of leather within a comparative short time. Realizing this possibility, the Council of National Defense requested the Bureau to compare the serviceability and wear of various kinds of composition and leather soles, with a view to the possible use of the former material instead of leather, should this become necessary. Many wearing tests were conducted by supplying soldiers at Camp Meade with pairs of shoes, one soled with composition and the other with ordinary leather. The results of these tests showed that there was little difference in actual wear among the composition soles, and that so far as wearing quality was concerned, the composition compared favorably with high-grade leather, but that the composition was not so serviceable as the leather and that wearing out at the toes, pulling out of the stitches, and cracking were common causes of failure of the composition soles.

Other experiments were made to determine the possibility of using half-soles of composition material instead of leather in repair work. It was shown that composition half-soles could be either

sewed or nailed to the shoes and that they would wear as well as leather, but as in the case of whole soles they would not be as serviceable, owing to the fact that they often became loose.

Investigation of Strap and Harness Leathers

Investigations along similar lines were conducted with strap and harness leathers, though in this case actual wear tests were impossible on account of the long life of the materials under the ordinary conditions of use. The preliminary investigations covered merely the immediate effect of different amounts and types of stuffing on the tensile strength of the leather. The data were insufficient to warrant any broad conclusions, as long-time effects should always be the criterion of value. As far as the immediate effect is concerned, the data show that the addition of stuffing to degreased leathers produces an increase in tensile strength as high as 20 per cent, and this increase depends more upon the viscosity of the stuffing mixture than upon the chemical nature of the constituents. This was strikingly illustrated by the fact that the two stuffings causing the highest increase in tensile strength were entirely different in nature, one being a mixture of petrolatum and paraffin, while the other was composed of wool grease, tallow, and cod oil. Their viscosities at room temperature were approximately the same. The addition of stuffing to leathers already containing some grease did not produce any appreciable increase in tensile strength when there was over 14 per cent of grease in the original. The amount of grease necessary to give maximum tensile strength varies with the leather and the nature of the stuffing used. Some tannages containing a small amount of stuffing (5 per cent) were strengthened by the addition of more stuffing, while others containing similar amounts were but slightly benefited by the addition of grease.

Chrome Retan and Bark Tanned Upper Leathers

A difference of opinion developed between our overseas and home departments regarding the proper upper leather to be used in Army shoes. The experts in this country were of the opinion that chrome-retan leather was more suitable, while the overseas supply office favored the use of bark-tanned leather. The Bureau was requested by the Hide and Leather Control Board and the shoe committee of the War Department to investigate the relative durability and waterproofness of these leathers in actual service. Accordingly, several pairs of shoes were made, one shoe having bark-tanned and the other chrome-retanned upper leather.

These shoes were placed on workmen whose duties alternately subjected the shoes to service under wet and dry conditions. The chrome-retanned remained more pliable, soft, and also more resistant to moisture. The results were reported to the War Department, which afterwards sent a special representative to Europe to investigate this problem. The result was that the chrome-retan leather was adopted as being more suitable.

The relative resistance of these two types of leathers to fermentation caused by mixtures of animal products was likewise investigated. This work was carried out in order to determine the relative fitness of the two types of leather for use in the trenches. The data indicated that the chrome-retan leather was much more resistant than the straight vegetable-tanned leather. The difference was greatest where the leathers were lightly stuffed, allowing the samples to be acted upon more strongly by the mixtures in which they were immersed. As considerable stuffing was removed from the leather by saponification, the use of unsaponifiable grease was recommended.

Transmission Belting

At the request of the standardization committee of the General Staff, the strength, amount of horsepower transmitted, water absorption, and resistivity to heat and stretch were determined for several types of belting made from rubber, leather, cotton, balata, and hair. The results were used in selecting the most suitable belting for field use.

Leather Packing for Recoil Cylinders

A leather capable of withstanding a high degree of heat is needed for packing in the recoil cylinders of large guns. A number of tests were made to determine the heat resistance of different leathers as affected by the character of the stuffing mixture. The most desirable sample proved to be chrome-tanned, and it appeared that the most resistant leather was the one having the highest degree of chroming. The test consisted of heating in oil at 225° C for a maximum period of two hours, though it is very doubtful if so high a temperature is ever attained in the cylinder. Various stuffing mixtures were tried for their effect on the leathers at this temperature. Samples stuffed with wool grease and petrolatum showed somewhat better resistance than pieces stuffed with other mixtures, but the difference in heat resistance was small compared with the differences observed between the various types of leather.

Waterproofing Materials for Use on Army Shoes

As a result of investigation on this subject it would appear that the waterproofing effect of a stuffing is approximately proportional to the amount of stuffing present up to a point where the pores of the leather are completely filled. Any water-soluble materials that can be introduced into the pores of the leather will increase its resistance to water, but there are many other things to take into consideration. About 40 per cent of grease will fill the pores of the cowhide upper leather used on field and trench soles, but the stuffing must have a rather high viscosity or it will be worked out of the leather and will require frequent replacement. The ideal stuffing should possess the following characteristics:

1. Not detrimental to the leather.
   (a) Free from detrimental impurities, such as acid.
   (b) Chemically inactive itself.
   (c) Not easily decomposed.
2. Should remain in the leather.
   (a) Nonvolatile.
   (b) High viscosity.
   (c) Not easily emulsified.
3. Insoluble in water.
4. Not stiffen the leather unduly, and make it more flexible if possible.
5. Not dry out hard or separate into its constituents on standing.

On account of the large variety of materials which will conform to requirement No. 1, there is an almost unlimited number of possible mixtures which should prove satisfactory. A number of these have been approved by the Bureau and several more have been suggested for use.

Shoe Cements

A satisfactory method developed at the Bureau for testing cements used in shoe manufacture is to stick two pieces of leather together with the cement to be tested and then to note the pounds pull required to separate the joints thus obtained. Although this was a comparative test, the results obtained check with what were considered commercially as the best materials, and thus aided the War Department in their purchases.

Shoe Laces

A comparative test of shoe laces was developed. It consisted merely of comparing standard Army laces and any new ones presented for adoption. The standard laces were of fabric construction with metal tips. Laces with cellulose tips and impregnated fabric were tested, but were found to be inferior to the standard lace. In conjunction with laboratory tests, actual service tests

were made on soldiers' shoes which gave conclusive results as to the best wearing lace.

Rubber Heels

A comparative test was made between leather heels with heel plates attached and rubber heels with metal plates vulcanized into them. The latter proved unsatisfactory and would not stand the rough wear, the heel plate gradually becoming loose and finally coming off.

Specifications and Routine Tests

At the request of the Signal Corps of the Army, specifications were prepared for the leather used in the construction of aviators' safety belts.

Representatives of the Bureau assisted the Committee on Leather and Leather Goods in developing standard specifications for all classes of leather. Many physical and chemical tests were conducted for the information of this committee. The Bureau offered the facilities of its laboratories for the testing of all lots of equipment leather purchased. Tests were made for the inspection division of the Ordnance Department of the Army to determine whether the samples submitted conformed to the standard set by the War Department. The work served to check the quality of the materials being delivered to the Government. The data obtained were of value to the Government, as they showed what variation could be expected in a single type of leather and how closely a leather could be expected to conform to specifications. They likewise helped the tanner to control his product and showed him where he was not getting the results desired. One hundred thousand dollars may be estimated as the amount saved the Government through this work. The Bureau examined a total of 2355 samples of leather and related materials, such as stuffing or waterproofing compounds, which consisted of a great variety of oils, greases, tars, rosins, and insoluble soaps. Waterproofing compounds were tested for their effect upon the leather and for their efficiency for the purpose desired. The routine test work may be tabulated as follows:

Tests requested by—	Number of samples examined	
	Leather	Other materials
War Industries Board	47	....
Ordnance Department, U. S. Army	1390	6
Quartermaster Corps, U. S. Army	900	12

The materials examined for the War Industries Board consisted of sole leather and shoes, while the work done for the Ordnance department was largely on harness, strap, back, and other equipment leather, as well as a few analyses of the stuffing materials used by the tanners supplying leather for the above purposes. For the Quartermaster Corps routine tests were made on harness leather and on upper stock, waterproofing, stuffing for Army shoes, leather soles, composition soles, laces, shoes, and rubber heels. Representatives of the Bureau were constantly in conference with officials of the Hide and Leather Control Board, the Shoe Committee and Supply Section of the Quartermaster Corps, the Committee on the Standardization of Leather and Leather Goods, the inspection division of the Ordnance Department of the Army, and the War Industries Board concerning the quality and testing of various leathers.

MAGNETIC INVESTIGATIONS

Magnetic Compasses

The Bureau cooperated with the Signal Corps and later with the inspection division of the Bureau of Aircraft Production in the development of testing methods for inspectors at the factories. These methods were established in the light of a preliminary investigation and test of 60 compasses submitted by the Signal Corps. Later, changes in the design of the instruments made necessary certain modifications of test methods and apparatus. The tests for performance included determinations of period, damping, magnetic moment, axis error, eccentricity, pivot friction, and effect of tilt. Specifications were prepared for apparatus suitable for the determination of these quantities and a set constructed.

The cooperation with the inspection division was continued by testing a certain small number of instruments selected by inspectors at the factory and sent to the Bureau for test.

The Bureau cooperated with the science and research and the engineering divisions of the Bureau of Aircraft Production in the development of instruments for American production by investigations covering certain specific points in the construction of the compasses. These points included the suitability of kerosene for use as a damping liquid, the possible strength of magnets obtainable with commercially available steel, the aging of magnets, and a suitable test for aging. The results of these investigations

were reported to the military authorities and utilized by them in the preparation of final designs and specifications. During the earlier stages of the work the facilities of the laboratory were made use of by members of the science and research division under the direction of officers of that organization. This work was later continued in other quarters furnished by the Bureau.

In addition to the work on the construction and testing of airplane compasses the Bureau gathered information and data on their compensation and behavior under service conditions. This was done by means of personal conferences with various pilots and other officers in the Air Service, by experimental flights, from official reports from various sources, and by laboratory experiments. The points covered had to do mainly with the so-called northerly turning error, the effect of liquid drag, vibration, etc. The information thus gained has been furnished to authorized parties by correspondence and conferences. A small collection of various types of instruments has been made which have been very useful for purposes of test and comparison.

The Bureau has cooperated with the engineering division of the Ordnance Department of the Army in the development of a lensatic compass for use as a marching compass and for artillery and machine-gun fire control. A sample compass of British manufacture was examined, and, as it had proved satisfactory in service, it was decided to use it as the basis of a design adapted to American manufacturing methods. Tests were made of the various performance characteristics, and a set of performance specifications were drawn up which were accepted by the Ordnance Department. Some problems which arose in the course of the manufacturing development were referred to the Bureau for solution. These points included the hardening and magnetizing of the magnetic needles, a satisfactory shop method for testing the strength of the needles, and the substitution of stellite for iridium in the construction of the pivots. These points were all satisfactorily settled and a good compass was produced. In addition to the development of the compass a test was made to determine the effect of the proximity of a machine gun on the indications of the compass.

Magnetic Analysis of Rifle-Barrel Steel

The investigation of rifle-barrel steel was undertaken in response to the request of the Ordnance Department of the Army. Due to unusual conditions of production as a result of the war the raw

stock for rifle barrels was found to contain a relatively large percentage of faulty material. The faults, in general, consisted of pipes or slag inclusions located at the center of the cross section of the bars. These faults were usually short, rarely extending more than 8 or 10 inches, and generally could not be detected until the barrel reached the drilling shop. The effect of these faults was to destroy the cutting edge of the drill, and thus make drilling of the faulty material impossible, sometimes even breaking the drill. The usual method of inspection consisted of selecting samples at random from a shipment of steel and making up from these samples a number of barrels. If more than a certain percentage of these barrels failed to drill properly, the whole shipment of steel was rejected. If it happened that the shipment was accepted as a result of these drilling tests, it was quite often found that a large number of barrels would get as far as the drilling shop and then be found to contain faults and this material was scrapped. It was thought that magnetic analysis offered promise as a nondestructive method of test by which portions of the material containing faults could be located and rejected before further work had been done. This would make possible not only the rejection of faulty material, but the acceptance of all the bars in a given shipment which were satisfactory, and thus effect a great saving of material and labor.

This investigation was carried out with the very hearty cooperation of the Winchester Repeating Arms Co., at whose plant final tests were made. The apparatus was designed, constructed, and tried out at the Bureau and then taken to the Winchester plant for final trial. The apparatus is constructed as follows: The bar under test is encircled by a magnetizing coil, which also carries what are known as test coils. The return magnetic circuit is composed of triangular cast-iron end plates and three iron pipes, which also constitute the frame of the apparatus. The test coils are connected to a recording apparatus, the operation of which is based upon the theory that if the bar is uniform mechanically along its length, it must also be magnetically homogeneous. If the bar is uniform magnetically along its length, the magnetic permeability at each point is constant for a given magnetizing force. In the test the magnetizing coil is energized by a constant direct current, thereby producing a constant magnetizing force at its center, and moved along the bar by means of a motor and cords at uniform speed. If the bar is magnetically uniform along

its length, the test coil will have induced in it no electromotive force, since the magnetic flux which it encircles will remain constant, while any variation from uniformity will be evidenced by a corresponding variation in the permeability. The flux will then vary at this point and an electromotive force will be induced in the coil which will be indicated by the recorder. Permanent records of these variations are made photographically. If instead of using a single test coil in the manner just described, two test coils are used, connected in series opposition, the record shows the variation of magnetic leakage along the bar instead of the variation of flux. The leakage is the rate of change of flux along the bar and is equal to zero if the bar is uniform.

Before taking the apparatus to New Haven it was set up in the laboratory and the effects of various types of flaws which were produced in various ways, such as by drilling holes, bending, and adding material of higher magnetic permeability, were studied. The apparatus was then set up at the Winchester plant in New Haven, Conn., and a large quantity of steel was tested. Practically no faulty material was found up to the time of the signing of the armistice, but some time later a lot of steel which showed magnetic nonuniformity failed to drill properly.

MANILA ROPE

No very pronounced demand for standardization among the specifications of the different Government departments for various materials had existed prior to the war. Large as the orders for such materials had been in normal times, the necessity for complete standardization was not very evident. When, however, as a result of the war many Government bureaus were buying goods of about the same kind at the same time, it soon became necessary to have some sort of standard specifications; otherwise many complications were bound to arise in ordering the same general class of goods for the different departments. As a matter of fact, in the early part of the war, such complications did arise and caused a great deal of confusion and loss. Even more serious than this situation was the necessity for the purchasing of large quantities of goods without adequate specifications of any sort. One of the items ordered in vast quantity by the Government, and which illustrates this last point, was manila rope. The situation in regard to the purchasing of this material in 1917 was an extremely serious one.

During that year, at the request of the Bureau of Construction and Repair of the Navy, a conference was called at which nearly all the reputable rope manufacturers and representatives of the Government bureaus were present. The object of the conference was to draft suitable standard specifications for manila rope, so that all the Government bureaus buying this material might be reasonably sure of what would be supplied to fill their orders. Prior to this time one of the common methods of specifying the requisite quality of rope was to state that it must be equal to the product of some reputable manufacturer. It is obvious that purchasing on such a basis is bound to result in dissatisfaction. No mention was ordinarily made of other elements of equality than tensile strength, and the requirements for strength of the various size ropes were as numerous as the bureaus using the material. The Bureau of Standards, which was represented at the before-mentioned conference, attempted to codify Government procedure in conformity with the manufacturers' standards, and as a result formulated the first draft of a set of rigorous specifications covering manila rope. This first draft was carefully considered, modified, and revised by the joint conference, with the result that the Government departments and the general public were provided for the first time with a comprehensive specification for good commercial quality manila rope. All important points are covered by these specifications, including the permissible grades of fiber, certified by the Government inspectors in accordance with designations of the Bureau of Agriculture of the Philippines (see the General Order of this Bureau No. 54, Nov. 15, 1917), maximum weight and minimum breaking strength requirements for various (circumference) sizes, permissible variations in circumference from rated sizes, the minimum and maximum allowable quantity of lubricant, the permissible tare weight in shipment, size of coils, and character of labeling of the shipment. In addition, the specifications give clear, concise methods for making inspection and tests and directions for imposing penalties or rejecting unsatisfactory rope.

The formulation of these specifications involved a great deal of work, since it necessitated the obtaining of both laboratory data and authoritative general information on manila and other fibers in the raw state and in the fabricated condition. The test for the detection of nonmanila fiber is in part a new chemical development used for the first time in connection with these specifications. It is a process which is quantitatively accurate.

MEDICAL SUPPLIES

Dental Amalgams

The increased demand for dental amalgams to be used in the Army, together with the question of quality of material submitted, resulted in the Bureau's being requested to make tests on the physical properties of a number of alloys.

The alloys supplied for making amalgams are usually composed of silver, tin, copper, and zinc in a ratio approximating 67:27:5:1. Variations of 25 to 30 per cent or the entire elimination of some one or more of the above metals is not uncommon. These alloy filings or shavings when mixed with an approximately equal weight of mercury will crystallize and form a mass of indefinite stability, depending upon the numerous conditions of composition, manufacture, and manipulation.

The resulting amalgam is sometimes slow in crystallizing and may never become rigid enough to withstand the stresses of mastication or to maintain proper contact forms with adjacent teeth. Some amalgams will expand markedly during the crystallization period, whereas others will contract excessively, either of which destroys the form and adaptation of the restoration. This change in form on the part of the amalgam causes seepage cavities to appear at the enamel-amalgam margin and is quite sure to result in the discoloration of the tooth tubuli, this discoloration being a good evidence of recurrent decay. Claims of disturbing electromotive forces are made against certain ratios of the elements as combined in the alloy. Further claims are based on the methods of cutting and annealing. With these conditions fully in mind, the Bureau undertook a systematic investigation of the field.

Dental literature is prolific in articles on the subject, and practically all of the manufacturers maintain testing staffs. (The latter proved very helpful to the Bureau during the progress of the work.)

The lack of concordant data on the subject, together with the absence of details of tests or instruments used in making these tests, made it necessary to repeat practically all previous work and to select instruments of greater precision, such that there could be no question about the results obtained.

After selecting and calibrating the instruments, tests were made on all alloys submitted under competitive bid to the Surgeon General. A few additional commercial advertised alloys and many special alloys were included. These tests included chemical

composition, chemical or crystallization changes (dimensional), crushing strength, tendency to flow under pressure, electromotive-force values, heat treatment of alloy, thermal expansion of amalgam and tooth materials, and other similar properties.

The results were submitted to the Surgeon General and awards were made on the basis of this Bureau's findings.

The details of this work, too lengthy to be included in this article, are given in Technologic Paper of the Bureau of Standards No. 157.

Briefly, it may be stated that no alloy has been found which could be considered as absolutely perfect, and that in many cases the specific claims made for alloys were found to be quite the opposite to those revealed in the tests. Probably the most significant discovery is the large value of thermal expansion of amalgams (about 25 millionths per degree centigrade) as compared to the much smaller value for tooth substance (about 8 millionths per degree centigrade).

Druggists' Rubber Supplies

A short description of the work in this field will be found in the article on "Rubber."

Dilution Pipettes

The Field Medical Supply Depot at Washington submitted a large number of dilution pipettes, which were examined and tested for accuracy. The apparatus received in the early shipments had a much higher percentage of rejections than that submitted at a later period. These pipettes were used in making up the proper solution for making the blood count in the hæmacytometer outfit. Various manufacturers sold pipettes to the Field Medical Supply Depot, and a large variation in the percentage of rejections was found, according to the party making the apparatus. About the time the armistice was signed a special lot of pipettes was submitted for test, and the percentage rejected exceeded any that had been tested previously. The Bureau requested that some other pipettes from the same manufacturer be submitted for test, and these were found to have errors of the same magnitude. As a result, an order for 3000 of these pipettes was canceled by the Field Medical Supply Depot, thus preventing the medical service from being furnished with inferior apparatus.

METALLURGICAL INVESTIGATIONS

Aluminum

One of the most important investigations taken up because of its military necessity and urgency was that of the technical phases

of the manufacture and properties of the light alloys of aluminum, both wrought and cast. Such alloys are of particular importance in connection with the design and construction of aircraft, since their lightness and strength well fit them for such service.

In order that the work of the Bureau might constantly best serve the needs of the military departments, close contact has at all times been maintained with them, both through the Light Alloys Committee of the National Advisory Committee for Aeronautics, by personal conferences, and through confidential reports.

One of the interesting results of this work has been the demonstration of the necessity for thorough investigation of fundamental facts and phenomena as the only satisfactory basis for technical progress in the art of manufacture. Thus at the outset the interpretation of test results was rendered extremely difficult by an almost total ignorance on the part of present-day metallurgists of some of the most fundamental physicochemical data on aluminum and its alloys. As the technical phases of the work have proceeded, it has been necessary to give increasing attention to its theoretical aspects, such as the problems connected with constitution, until now it appears that further progress depends upon the solution of several of these fundamental questions.

The investigational work has been carried out along several different lines, among them being the following:

An investigation of aluminum-rich alloys of three ternary alloy systems has been conducted with the object of developing better commercial rolling alloys for use in structural construction. A survey was made of the mechanical properties of the rolled aluminum-rich alloys of magnesium with copper, nickel, and manganese. From 8 to 12 compositions of each system were cast and rolled into sheet at the New Kensington plant of the Aluminum Co. of America, a representative of the Bureau directing both the preparation and subsequent testing of the samples. The copper series proved so superior in respect to mechanical properties in these tests that the other two series have been practically eliminated from further consideration for purposes for which high strength is desired. Likewise it is the only series particularly adapted to heat treatment. The results of this investigation are described in Technologic Paper No. 132.

Heat treatment of the alloy known commercially as "Duralumin" has been practiced for several years, but apparently little improvement has been made in the actual heat-treatment practice

since the initial discovery of this property of the alloy by Wilm. The Bureau's investigation of this question has led to some very interesting discoveries bearing on the theory of the effect of this treatment. Important alterations in existing practice of commercial heat treatment have been brought about, resulting in improved physical properties and reduced wastage from cracking during treatment. These alterations have been adopted commercially, and the results of this work are being published in Scientific Paper No. 347.

Researches of a military character at the Bureau showed the existence of remarkable properties in the metal and its alloys when aluminum purer than that commercially supplied was employed. Accordingly, special apparatus was devised and materials assembled at the Bureau for carrying on an investigation of this subject. The apparatus used for the electrolytic production of aluminum consists of a steel crucible having a pure Acheson graphite liner for holding the electrolyte and a gas furnace for keeping the contents of the crucible molten. A movable Acheson graphite rod, set axially in the crucible, serves as the anode, and the crucible is arranged so that the aluminum can be tapped off as desired.

Tests have been made of different casting alloy compositions from the Bureau's foundry (1) to discover alloys which will give better mechanical properties than those in use at present, (2) to study the effect of heat treatment on these alloys, (3) to ascertain the effect of the impurities, iron and silicon, on the properties of the alloys in the cast form, and (4) to study the effect of melting and casting temperatures on those properties. The results indicate the possibility of obtaining alloys which are both harder and at the same time more ductile, hence tougher, than those in use to-day. This is accomplished both by the choice of a more suitable composition and the application of heat treatment.

The necessity for clearing up a number of questions relating to the structure and constitution of aluminum and its light alloys has become increasingly apparent. The fact that further progress in the art of the manufacture of the alloys depends upon the correct solution of fundamental problems is now well understood and has led to the undertaking of the determination of (1) the structural identity of the constituents of the alloys of aluminum with iron, silicon, copper, magnesium, manganese, and nickel, and (2) the solubility at different temperatures of these constituents in aluminum in solid solution. These results, together with the

data of previous investigators, practically complete our knowledge of the constitution of the aluminum-rich alloys of these metals, and will serve to direct further work in the choice and development of commercial alloys.

The work to date has shown the superiority in strength of both casting and rolling alloys containing either zinc-copper or magnesium-copper as an addition to aluminum. Since, when this investigation was undertaken, the National Physical Laboratory was studying the zinc-copper combination as applied to rolling alloys, the Bureau's efforts were directed to the improvement of the Duralumin type of alloy, either by slight alteration of composition or by alteration of heat treatment.

The study of entirely new rolling alloy compositions is considered unnecessary for the present. The results of the above investigation are included in Scientific Paper No. 337.

Another problem that will be undertaken is the possibility of spot welding duralumin. At present beams and other structural members of duralumin for aircraft construction are assembled by riveting. It would be desirable to expedite the production of such members by spot welding of the component parts, if this process could be shown to produce reliable joints.

In addition to the work above outlined the behavior of duralumin and commercial light aluminum casting alloys, of great importance in aircraft construction, received some attention.

One of the problems in which the National Advisory Committee for Aeronautics and also the Navy Department were greatly interested was the effect of corrosion, particularly under sea-water conditions, on aluminum alloys such as those used in airplane manufacture. A systematic program of experiments and exposure tests was started and is still under way. A number of the alloys covered with various protective coatings, together with unprotected sheets, are being exposed to the action of the atmosphere and sea water at three widely differing latitudes to determine the best alloy and coating to be used in seaplane construction.

The Morris engineering process for the liquid forging of light aluminum alloys was investigated in cooperation with the Naval Gun Factory, Washington, D. C. This process gives a highly satisfactory alloy for aeronautic purposes and one which is greatly superior to cast or die-cast metal, being of increased strength and ductility and free from blowholes and other inperfections.

The Bureau of Aircraft Production was very much interested in the problem of the corrosion of aluminum carbureters. Its

importance lies in the fact that particles of sludge resulting from the corrosion which takes place in the float chambers of aluminum carbureters are apt to lodge in the nozzles, thus stopping the flow of gasoline. The relation of the composition of cast aluminum to corrosion is being studied, and various protective coatings are being investigated.

For the information of the military departments there were prepared the following circulars: No. 76, "Aluminum and Its Light Alloys"; No. 78, "Solders for Aluminum"; "Circular Letter on Proprietary Aluminum Alloys."

Research in Connection with the Welding of Steel

Several national bodies have been interested in furthering our knowledge of means for improving welding methods, and in this connection the Bureau has worked in cooperation with the electric-welding committee of the American Welding Association. The metallurgical division has been concerned with such questions as the outlining of specifications for metallographic examination and with the experimental study of the relations of structure to brittleness in welds. This work is being carried out both on material of American manufacture and material furnished by the British Admiralty. The resistance to corrosion of different types of welds, including their solubility in acids, has also been investigated. It appears that a welded joint of the usual type will corrode no faster than a riveted one. It is planned to include in this investigation a study of the effects of the presence of gases entrained in welds; the identification and role of certain constituents considered harmful, such as the nitrides of iron, and the development of nondestructive tests for welds. Incidentally, a considerable number of welds of various types have been prepared for physical tests.

Copper Crusher Gages

At the request of the Society of Manufacturers of Small Arms and of the Ordnance Department, the Bureau prepared specifications for copper crusher gages for testing ammunition and aided in standardizing the methods of use. A considerable amount of experimental work was also carried out on the characteristics of copper crusher cylinders, particularly as related to their properties under various conditions of annealing and as dependent upon precompression, and included a study of the resulting errors. A publication on this subject is in press.

Machine-Gun Erosion

At the request of and in cooperation with the Ordnance Department of the Army, a systematic study was undertaken of the problem of gun erosion from the metallurgical point of view, and particularly as applied to the design, material, and operation of machine guns. A series of special steels was made up into gun barrels and subjected to various physical and ballistic tests.

The details of the erosion phenomena have also been investigated along several new lines of attack.

Identification Tags for the Navy and Army

Early in 1917 an investigation was commenced at the request of the Bureau of Identification, Navy Department, to determine the types of metal suitable for individual identification tags. As a result of this work monel metal was recommended for this purpose, and a method was also devised of obtaining a permanent finger-print record on monel metal. The Navy Department adopted the Bureau's recommendations and similar action was later taken by the Army.

Tests of New Alloys

As a result of the war a number of new alloys, or modifications and processes with new names, were brought out. Some of these have been submitted for examination, usually with a view to their military utility. Among them may be mentioned: "Liberty metal," palau, rhotanium, various aluminum solders, acerial, magnalium, magnalite, McAdamite, cooperite, al-calcium, magnolia metal, ulco-bearing metal, various metal coating processes, the alloys dirigo, bario, cosmic, zelco, stellite, tinol, aterite, sperlite, Silliman bronze, etc.

Gold-Palladium Alloys as Substitutes for Platinum

The high cost and scarcity of platinum greatly stimulated, especially during the war, the production of "platinum substitutes" for various purposes. Of those intended for use as chemical-laboratory ware no alloy of base metal so far tested has been found suitable. Two alloys of gold and palladium have been placed on the market and have come into more or less general use. These are known as "palau" and "rhotanium."

A series of tests has been carried out to determine the suitability of these alloys as substitutes for platinum in laboratory ware. The behavior of crucibles made from the above alloys on heating to 1100° and 1200° C in an oxidizing atmosphere was determined,

and the effect of the various chemical reagents was studied. The results indicated that in many instances these alloys could replace platinum very satisfactorily, thus releasing a large quantity of this metal for other purposes. A preliminary article on this subject appeared in the Journal of Industrial and Chemical Engineering (II, p. 570; 1919).

Nickel Spark-Plug Electrodes

A study of the deterioration of the nickel terminals of a certain make of spark plugs used in internal-combustion engines was made at the request of the manufacturer, and was later extended to include other types of plugs. The brittleness which results in the electrodes upon usage was shown to be a characteristic property of nickel wire and must be expected to occur to some extent in all types of plugs. Deterioration is much more rapid in some types than in others, due to the stresses to which the wires are subjected while hot. These stresses, in turn, depend upon the arrangement and shape of the electrodes. The results of the study are given in Technologic Paper No. 143.

Cements for Spark-Plug Electrodes

The use of cements for welding electrodes to spark-plug porcelains has been found to be attended by various difficulties in high-temperature engines such as are used in airplanes. Among these difficulties are the promotion of oxidation and destruction of electrode wires by reactions taking place in the cements and between the cement and electrode wires; the breaking of porcelain caused by difference in coefficients of thermal expansion of electrode wires and porcelain; and the cracking of cement with consequent gas leakage, due to the same cause. A cement composed of silicate of soda and raw kaolin has been found to give little trouble from chemical action. In order to avoid the difficulties attending the use of any form of cement, the employment of a mechanical seal at the top of the porcelain has been tried with promising results.

Conservation of Manganese

Two lines of research which were initiated during the war with a view to economizing in the use of manganese in steel manufacture are still being carried on. These investigations include: (1) The making of a series of alloys of iron, carbon, and manganese, using pure materials, and the testing of alloys for physical properties in the heat-treated and annealed condition, with the object of revising

the specifications for certain steels whereby their residual manganese content can be much decreased, and (2) an investigation in cooperation with the National Research Council and others whereby substitute deoxidizers, such as various combinations of the deoxidizing elements of silicon, aluminum, titanium, and manganese, will be tried for making steel. The steel so made will be rolled and forged in the Bureau's plant and then tested for physical and other properties. A small open-hearth furnace of 500 pounds capacity was designed and built for this purpose.

Oil Proofing Concrete Liners

At the request of the Emergency Fleet Corporation, work was undertaken to find a means for rendering concrete ships impervious to light mineral oils. The methods suggested were to cover that portion of the interior of the hull in which the oil is carried with lead sheets, cast lead, sprayed lead, shellac, neat cement shot from a gun, barium sulphate, or sodium silicate. Experimental investigations, started on what seemed to be promising lines, were eventually discontinued as impracticable, due either to porosity or excessive weight of the covering material.

Tin Conservation

All the tin used in the United States is imported, and during the war a shortage of this material appeared very probable. The Bureau, in cooperation with the War Industries Board, held numerous conferences and carried on extended correspondence with manufacturers and consumers of articles containing tin, as a result of which a program was drawn up limiting its use and encouraging the development of substitutes. The experimental work has included the finding of suitable solders, the reduction of tin in bearing metals, modifying bronzes with respect to tin contents, and recovering tin scrap. Suggestions to the Government departments concerning modification of specifications with the object of conserving tin were likewise made.

Cadmium Solders

From this investigation it was found that cadmium solders of the four compositions shown in the accompanying table may be

Metals	I	II	III	IV
Pb	90	80	85	75
Cd	10	10	10	10
Sn	....	10	5	15

used to solder tin plate, terneplate, brass, and copper as successfully as the ordinary tin-lead soft solders. The manufacture and use of the 90–10 mixture is rather difficult, due to the extreme ease with which it oxidizes in the molten condition. The preferred composition is 80 per cent Pb, 10 per cent Cd, and 10 per cent Sn, and it has been tried out with success on roofing materials and tin cans, while tests on fire extinguishers and automobile radiators are now in progress. A patent dedicated to the public was taken out on this solder.

Bearing Metals

Service tests of different compositions of bearing metals, especially those not containing tin, were made to determine the adaptability of certain lead-base babbitts hardened with alkali or alkali-earth metals. It was found that in some respects they were superior to genuine babbitt, and their use is being recommended in certain cases.

The information assembled on this topic ana the results of these few tests which have been made on special bearing metals indicate a need for a systematization of our ideas concerning bearing metals in general and the advantages and disadvantages of different types, as well as of more extended study of the behavior of different compositions of both babbitts and bronzes in service. A circular is in preparation dealing with bearing metals, and Technologic Paper No. 109 gives an account of the work of the Bureau on conservation of tin in bearing metals, bronzes, and solders.

Metals for Aeronautical Instruments

A study was made of the composition and thermal treatment of metals suitable for certain aeronautical instruments, such as recording barometers, altimeters, etc., with the object of diminishing the elastic after effects which are usually so troublesome.

In this connection the behavior of cold-worked nickel-brass, which is used largely for the diaphragms of these instruments, was examined. In the cold-worked sheets the "work lines" to which the hardness is due are very pronounced. Upon annealing these "work lines" are gradually erased; heating for 20 minutes at 500° C. is sufficient to remove them entirely. The disappearance of these lines or bands may be taken as an indication of the rate at which the hardness due to mechanical working is removed. Above 500° C. the nickel-brass increases rather rapidly in grain size and becomes soft and ductile.

A suitable spring for altimeters was developed, using a high-silicon nickel steel having an elastic limit well above 100 000

pounds per square inch. This spring when tested in an instrument under conditions duplicating an ascent to an altitude of 25 000 feet, showed an absolutely constant zero and no elastic after effects.

Diaphragms and springs of various metals and alloys which had been given different thermal treatments have been and are being subjected to various types of loading in order to obtain a comparison of their elastic properties, and also to determine the best metal for such conditions of service, thereby improving the precision of the instruments in which they are used.

Of the numerous nonferrous alloys investigated the most promising for the construction of diaphragms is aluminum-bronze with 7 per cent aluminum content. A study is also being made of the hysteresis of steel springs and of its elimination. The work done to date on elastic hysteresis leads to the probable conclusion that it is caused by overstrain. The theory has been developed in detail.

Test-Bar Fractures

During the war the Ordnance Department of the Army accumulated a very considerable number of fractured test bars as the result of examination of many thousands of samples of steel. The Bureau undertook, in cooperation with the technical staff of the above department, a statistical and systematic study of the fractures produced in tension and of the methods of photographing, in order to furnish an explanation and description of the various characteristic features and to relate them with the structure of the tension bars. The aim was to embody the results of this work in the form of a manual which could be furnished to inspectors.

Hardness of Brass Cartridge Cases

An investigation of the hardness of brass cartridge cases by means of the micro-Brinell hardness machine developed by the Ordnance Department during the war was carried out by the Bureau. The hardness investigation was supplemented by studies of the microstructure of the material, its mechanical properties, mainly in tension, and its behavior as regards corrosion cracking. A considerable amount of work was also done by the Bureau in the examination of cartridge cases to determine the effects of various methods of manufacturing upon the properties of the finished material and with a view to aiding the Ordnance Department in its inspection and specification service.

Centrifugal-Steel Castings

As a possible means for securing superior steel castings, it was considered desirable to study the properties of ingots cast by the Millspaugh centrifugal method. This method produces an ingot of hollow cylindrical form, and it was thought that there would be a considerable saving of material, labor, and time in the manufacture of cylindrical steel appliances. If the method warranted, it was hoped that cast or heat-treated cast material made by this centrifugal process could be substituted for forged pieces. The castings submitted for examination were a miscellaneous assortment of four, having several chemical compositions and cast under various conditions, none of them being cast strictly in accordance with specification requirements for ordnance material. Very interesting and promising results were obtained, among them the following:

Segregation of the elements—carbon, sulphur, and phosphorus—appears to exist only radially and is confined mainly to a very thin layer of the inner zone, but exists also slightly in the outer zone. Nickel also appears to segregate somewhat, following the carbon. The maximum carbon segregation found amounted to 0.09 per cent in a steel containing 0.66 per cent carbon and nickel 2.2 per cent. Blowholes appear only in the inner segregative zone. The density across a section is practically constant; tensile and shock tests show in general greater strength and elasticity, but less ductility in tangential than in longitudinal directions. This method of casting develops very slight internal stresses. By suitable heat treatment the physicial properties of steel cast by this method compare very favorably with forged material of the same composition. The metal of the casting is clean and sound, and its microstructure better than in ordinary types of steel casting.

Magnesium-Aluminum Alloys for Mirrors

The Signal Corps and the Corps of Engineers of the Army were much interested in the development of a light metallic mirror material of high-reflecting power, and it was desired, if possible, to realize mirrors as large as 6 feet in diameter. The Bureau undertook the investigation of aluminum-magnesium alloys for mirrors, and, although it was found impracticable to build such large mirrors, it was found that the compound Al_3Mg_4, containing 50 per cent magnesium, gave a reflection of 85 per cent in the blue and 93 in the red portions of the spectrum, and could be made mechanically satisfactory by a vacuum melting

and heat treatment. Although this alloy is much more resistant to the action of dilute acids and alkalis than any other AlMg alloy known to the Bureau, it is not recommended where permanency is of prime importance, as some of the samples showed evidences of slight contamination after standing several months in the laboratory. (See Scientific Paper No. 363.)

Steel Helmets for the United States Army

Two questions which were presented for solution by the National Research Council in connection with certain problems arising in the manufacture of steel helmets were investigated by the Bureau and may be described as follows:

1. It was desired to determine whether heating up to quenching temperature in the treatment of helmets following the pressing operations was sufficient to remove the stresses set up during the pressing. The average results of tests showed that the heating of test pieces of helmet steel to 825° C, followed by rapid cooling in a furnace, reduced the amount of stresses by about 60 per cent, while those test pieces heated to a like temperature and cooled slowly in a furnace showed a reduction of some 73 per cent as compared with the amount of stresses found present in the test pieces which were not heat treated; that is, in the original or pressed condition.

2. The length of time needed to hold helmet steels at the quenching temperature to get full hardening on quenching was also determined. Helmet steels of 11 compositions were examined to find their critical ranges in connection with the development of tests for determining their resistance to deformation and penetration.

Effect of Prolonged Annealing High-Silicon Cast Iron

The inspection division of the Ordnance Department of the Army, which was interested in the use of noncorrodible iron of the type of "duriron" (cast iron of the approximate composition—total carbon, 1.18 per cent; graphite, 1.09 per cent; silicon, 13 per cent, requested the Bureau to determine the possibility of any changes in composition upon continued heating. The examination showed that continued heating for as long as 50 hours at 1000° C produced no essential change either in structure or composition.

Horseshoe Nails

At the request of the General Engineer Depot of the Army, an examination was made of horseshoe nails, representing most of

the manufacturers of this class of material, with the aim of drawing up specifications. The examination showed a rather wide variance in the type of steel used (0.07 to 0.20 per cent carbon), and in the process of manufacture, some being hot-forged while others were cold-stamped. A simple type of impact tests, using a notched specimen, was recommended for determining the relative merits of different types of nails.

Deterioration of Nichrome Castings upon Heating

The attention of the Bureau was called to this problem by the Chemical Warfare Service. The large nichrome castings in the form of tubes used for the production of charcoal for gas masks deteriorated rather rapidly in service, becoming weak and brittle. The examination made of the material showed that, contrary to the opinion expressed by other investigators of this problem, the deterioration does not consist in the formation of a carbide by interaction with the charcoal. On the other hand, the carbide normally present in the nichrome is removed. An intercrystalline brittleness apparently identical with that found in nichrome wires after continued heating is produced, the exact nature and cause of which have not yet been determined.

Light Armor Plate

In cooperation with the Bureau of Mines and the Navy Department, the properties of special alloy steels suitable for the development of light armor are being studied. The majority of these steels contain zirconium, while others contain molybdenum, boron, cerium, etc. About 150 ingots have been made by the Bureau of Mines experiment station at Ithaca, N. Y., and have been rolled into plates of three-eights or one-half inch thickness at the Bureau of Standards. These materials are being thoroughly examined to determine their mechanical, chemical, and thermal properties, effects of heat treatment and annealing, hardness, resistance to impact, and microstructure. In conjunction with the ballistic tests to be made by the Navy Department, valuable and useful data will be obtained for the design of light armor plate.

The Relative Cutting Properties of "Cooperite" and "Stellite"

At the request of the Bureau of Ordnance, Navy Department, a test was undertaken to show the relative cutting properties of the alloys "stellite" and "cooperite." These two alloys, though quite different in chemical composition, have very similar mechanical properties—they are very hard and able to "keep an edge" at a rather high temperature. Stellite in particular is

used quite extensively to replace and supplement high-speed steel tools for cutting. Cooperite is essentially an alloy of nickel and zirconium, with appreciable amounts of iron and silicon. Stellite, which is manufactured in several different grades, is a rather complex alloy, the essential elements of which are cobalt, chromium, tungsten, and molybdenum.

The series of service tests made showed that cooperite is but slightly inferior to the better grades of stellite. Lathe tools made of cooperite failed after a cut of 4-inch length made on a 5-inch round of nickel-chromium steel.

Miscellaneous Investigations of Iron and Steel

At the request of the inspection division of the Ordnance Department of the Army, an extensive and detailed study of the defects in steel slugs intended for the manufacture of shrapnel cases, as revealed in the fracture caused by the "nick-and-break" test, was made. This was supplemented by a study of slugs which had been sheared as well as broken by the "nick-and-break" test, the aim being to show whether shearing could be substituted for the latter method in the work of inspection. The results of the examination, however, did not appear to warrant a recommendation from the Bureau in favor of the proposed change in the method of inspection of this class of materials.

An investigation with the object of determining the harmful effects of pickling, cleaning, and plating on wires, thin rods, and sheets of various grades of steel submitted to several heat treatments was originally undertaken in connection with the preparation of specifications for aircraft parts. Experiments dependent upon the tensile tests as a criterion failed to measure properly the embrittling effect produced by pickling, and although the impact test on notched bars was also investigated, it was found that no constant results could be obtained. Alternating-stress tests of 0.30 per cent carbon steel showed that pickling in sulphuric acid reduces the resistance to fatigue by more than 30 per cent for rods ranging in diameter from one-eighth to three-eighths of an inch. Steel rods three-sixteenths of an inch in diameter and with a carbon content varying from 0.09 to 0.87 per cent showed similar reductions in resistance to fatigue. Analogous results were obtained by the Erichsen test on sheet steel of various thicknesses and hardness. Brittleness gradually decreases at room temperature, but recovery is not complete although hastened by heating. Brittleness caused by pickling appears to

be the result of two effects combined: (1) A temporary effect supposedly dependent on hydrogen; (2) a permanent effect caused by the roughening or etching action of the acid. The effect of plating upon material which has been cleaned, pickled, or sand-blasted has also been studied.

An investigation of the most suitable steels and treatments for the manufacture of precision gages, resulting from work originally carried out for the War Department, is in progress. The work includes the determination and comparison of resistance to wear, permanence, resistance to corrosion, soundness, expansibility, and economy of different steels under varying thermal treatments.

Examinations were made of numerous specimens of defective gun steel and airplane crank-shaft stock which exhibited the type of defect known as "flakiness." This defect takes the form of a shining, coarse, crystalline area in the midst of otherwise sound material. The flake, which may be as large as 1 cm in diameter, has the appearance of an inter-crystalline discontinuity in the steel and is very often (if not always) associated with steel which is badly contaminated with slag and similar inclusions. "Flakes" reduce the ductility of steel, although the ultimate strength of the material (in tension) is not affected to the same extent, and are particularly injurious in material exposed to repeated stresses. The study of this material is being continued, and particular attention will be given to the effect of forging and heat treatment upon such material. A preliminary publication was made from the American Institute of Mining and Metallurgical Engineers in February, 1919.

As it has been found that a prolonged acid attack may reveal imperfections in steel, a study of the deep etching of iron and steel designed for various uses has been undertaken. It is hoped to show the influence of the various possible factors, such as chemical heterogeneity (segregation), physical heterogeneity (variations in crystal size, presence of intercrystalline discontinuities, etc.), and mechanical heterogeneity (internal stresses, etc.). The study of the macrostructure of metals has in general received much less attention from metallographists than the microstructure. "The Metallographic Features Revealed by the Deep Etching of Steel" has been published as Technologic Paper No. 156.

Laboratory and service tests were made on several types of high-speed tool steel and their substitutes including cooperite,

stellite, and "cobalt chrom." These tests showed that the various modifications and substitutes, although possibly possessing advantages for special uses, are in general not to be preferred to the more familiar types of "tungsten-chrom" steels for cutting purposes. An interesting advance in the manufacture of high-speed tools was the perfection of a method by which such tools are produced direct as castings, thus eliminating the costly and time-consuming grinding processes hitherto required for shaping them. Tests of cast tools showed that they give service equally as good as those made in the usual way.

Preparation of Specifications

In the formulation of specifications for all kinds of metal articles, the Bureau was frequently called on for advice by the military departments interested in the work. The preparation of such specifications often necessitated experimental investigation. Among the numerous cases of such assistance, the following may be mentioned: Specifications for shells, cartridge cases, pressure plugs, metals for aircraft parts, welding electrodes, coated metals, metals for tanks, horseshoe nails, rotating bands, bearing metals, surgical instruments, instrument metals, Army hardware, etc.

Foundry Research and Production of Castings

The Bureau's experimental foundry (Fig. 17) was extremely useful during the war, as it produced many special castings for instruments and other devices, which were used in numerous lines of research both at the Bureau and in the laboratories of other Government departments where military development work was being conducted.

Thus, for the fiscal year ended June 30, 1918, the foundry made the following castings for experimental and special technical uses, mainly military:

Metal	Castings	Patterns	Weight
			Kg
Aluminum alloy	255	76	138.63
Brass	241	84	420.75
Bronze	1701	334	1244.50
Cu-Mn-Ni alloy	1	1	12.00
Copper	6	4	132.00
Lead	10	5	33.80
Silver alloy	1	1	6.56
Tin	21	3	39.50
Zinc	13	8	424.53
Total	2249	516	2452.27

In addition, investigations of certain new types and modifications of old alloys were carried out on an extensive scale for the military departments. Work was also undertaken on the reclamation of burnt steel foundry sands, with the object of saving transportation costs. This investigation, however, was not pushed to a conclusion.

Work for the Ordnance Department of the Army

As an illustration of the type of work which was carried out in detail for several of the military establishments during the war, that performed for and in cooperation with the Ordnance Department may be cited as an example. The several experimental researches and investigations are described elsewhere, and only the very considerable amount of testing which the Bureau conducted will be considered in this paragraph. The gun section of the Ordnance Department provided considerable equipment for carrying out routine tests of gun steel. These were made to supplement and explain results obtained in the tensile tests of samples taken from gun forgings, and to show the heat treatment suitable for controlling the microstructure of large guns during the forging operation. Examinations showed that the heat treatment of the gun forging had been, on the whole, satisfactorily carried out, and that the inferior properties encountered were generally due to the nonmetallic impurities. Similarly, a systematic series of tests (including several different methods) was made on 3-inch brass cartridge cases, representing the product of several manufacturers. Other work included a general study of the defects in slugs intended for the manufacture of shrapnel cases, examinations of copper rotating bands for shells, and studies of a great many samples of failed metals for ordnance purposes.

Miscellaneous Metallurgical Investigations for the Military Departments

The more elaborate investigative tests for the military departments included an examination of the characteristics of centrifugally cast steel, which gives promise of possibilities of advantageous use in replacing several lines of steel forging, in cutting down discards, in reducing machining and segregation, and in eliminating piping, blowholes, and forging; a study of strains in cartridge cases, as dependent on manufacturing methods, and the adaptability of accelerated stress-corrosion tests for predicting failure; the relation of grain size to distortion in cartridge cases; an exhaustive comparison of the relative merits of cold

FIG. 17.—*The experimental foundry*

Gas and oil heated furnaces for nonferrous alloys are shown at the left. The Bureau investigated the properties of nearly all the metals and alloys used in military construction work

FIG. 18.—*The specially designed rolling mill used in studying the behavior of metals under working conditions*

The complete process as carried out in the mill can be studied under easily controlled conditions, something which is not possible in a commercial plant

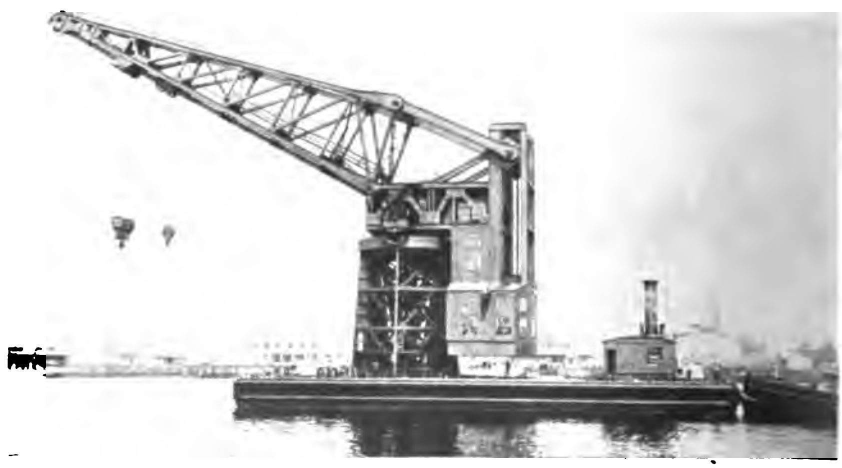

FIG. 19.—*One-hundred-and-fifty-ton floating crane at the Norfolk Navy Yard*

Strain-gage measurements on this crane were made by representatives of the Bureau to determine the stresses in the various members

shearing and nick-and-break method of test for shell slugs; methods for distinguishing between hard and soft rotating bands for shells; several tests of armor plate, and numerous other materials for Ordnance, Aircraft, Quartermaster, and Engineering Departments of the Army, and for the various branches of the Navy; tests of fusible tin boiler plugs for steam vessels; a study of methods for the recovery of tin; and examination of a very large variety of coatings for rust-proofing. Interesting features of these investigations were the nonuniformity in electroplated coatings, uniformity of sherardized coatings; information concerning brass plating, the relations among the metals showing the superiority of zinc; and a study of the "copper-clad" process; microexamination of large (12-inch) chain links forged, welded, and cast, and tarnishing tests on Benedict nickel and German silver. Among some of the special problems were the heat treatment of very small compass needles, large (30-inch) U bars, long, slender rods, and very large sheets; service tests of the lead-base bearing metal "Ulco;" service tests of a special lead-base babbitt; investigation of the cause of failure by cracking of brass locomotive steam-gage tubes; cause of cracking of casehardened aeroplane engine-cam followers; failures of aeroplane crank shafts; service tests of rhotanium and palau (substitute for platinum) crucibles; corrosion tests on several acid-resisting alloys; tests of numerous commercial light aluminum alloys; causes of cracking of welded Army aluminum canteens; determination of working temperatures of machine-gun barrels; and tests of magnalium alloys of high optical reflectivity for mirrors, including the preparation of a series of such alloys. A large number of steels and alloys were examined by thermal analysis to locate their critical points; the processes for the casting of numerous metals and alloys for instrument parts were studied, and samples of meteoric iron were examined to determine their structural characteristics. Numerous samples of platinum were tested to determine purity and causes of deterioration; a very serious type of failure known as "flaky" steel occurring in nickel-chromium and nickel-steel was investigated in great detail, while semisteel, cast iron, and steel shells, failed gun forgings, and other ordnance material were studied to determine the cause of failure, suitablity for use, or special characteristics. Other work was carried out on valves for aircraft motors, machine-gun barrels, German rifle bullets, cartridge clips, samples of Duralumin alloy used in Zeppelin construction, zinc coatings on

shrapnel timing leads, causes of cracking of steel rivets, and identification tags of Monel metal for seamen. In all this work the unusually complete equipment of the Bureau's laboratories (Fig. 18) was of great assistance.

Military Inventions

The metallurgical division has assisted the various Information bureaus of the military departments, as well as the Patent Office, in the examination and development of military inventions relating to metals, manufacturing processes, and various devices made of metal.

Information Furnished by Correspondence

In addition to information furnished in personal interviews on military and technical subjects, a very heavy correspondence was maintained on questions relating to metals, some of the advice given in this way being of considerable importance.

Membership in War Boards and Military Committees

The metallurgical division rendered valuable service in problems of national defense through membership on numerous boards and committees.

Among the activities of importance may be mentioned particularly that of the chief of the metallurgical division as the representative of the Department of Commerce on the requirements division of the War Industries Board. This enabled the Department to take an active interest in and to secure valuable assistance on many exceedingly important matters coming before the Government. Four months were spent abroad by this member of the committee in the spring and summer of 1917, while serving on the scientific mission sent to obtain information concerning applications of science to warfare and the part to be played by scientific men in the war. The information thus gained proved of inestimable value in planning investigations in the United States.

Another member of the staff was very helpful as adviser in ceramics to the War Industries Board and assisted in framing specifications for enameled ware as a member of the Army committee on standardization. Another rendered valuable service as a member of the Interdepartmental Committee on Minerals and Their Derivatives, and also aided in the manganese-conservation program. The committee on light alloys of the National Advisory Committee for Aeronautics carried out most of its experimental work through the Bureau of Standards, and the results of this have appeared in a series of publications. The National Research

Council has actively cooperated with the Bureau in several military problems, and the Bureau's representatives have been active on 11 of its committees, among these one of the most important being a committee to make a survey and recommend practice as to the ingot and finishing practices of American steel mills. This work originated in the Ordnance Department of the Army in connection with the works practice as influencing the output of steel.

Various members of the metallurgical division were called in as technical advisers by the several branches of the War Industries Board, particularly on questions relating to tin, steel, and platinum, and the Bureau of Standards in consequence has undertaken considerable experimental investigation, especially on tin conservation and substitutes.

In addition to formal committees with regular programs there have been held a great many conferences at which the Bureau of Standards' representatives have been present, called by the various military departments to discuss with manufacturers technical questions bearing on military materials and specifications.

PHYSICAL TESTS OF METALS AND METAL STRUCTURES

Load Tests of 150-Ton Floating Crane for the Navy

At the request of the Bureau of Yards and Docks of the Navy Department, engineers of the Bureau of Standards conducted a loading test and strain-gage analysis of the 150-ton (336 000 pound) revolving floating crane built for use in the navy yard at Norfolk, Va. (Fig. 19.) The test was made to determine the stress distribution in the various members of the structure while under load and to obtain a more complete knowledge of the actual amount of the stresses in some of the members of such a statically indeterminate structure.

This Norfolk crane represents the most advanced type of revolving floating crane of large capacity. The jib is a tapering Pratt truss, and the balance of the superstructure consists of two subdivided triangular trusses rigidly connected by cross-bracing. The entire revolving load is carried on a pintle which transmits the load to a thrust bearing on the deck of the pontoon. The pintle is supported laterally by a hexagonal tower which is constructed integrally with the framework of the pontoon.

The method of stress analysis used in this investigation parallels that used in the load tests of the Arlington building (described in the article on cement and concrete) and is the same method which has been so successfully used in the study of bridges, steel frame-

work of buildings, and similar engineering structures. A Berry strain gage was employed to determine changes of length of established gage lines by comparison with standard reference bars. With known moduli of elasticity for the materials in question, the unit deformations may be converted to the corresponding stresses. In the hands of trained observers such an investigation yields results of great value for future designing work.

Readings were taken at various points of the deck to determine the magnitude, and, if possible, the position of maximum stress in the upper deck plate; on the tower members to determine whether the tower acted as a unit; around the manhole in the tower legs to find the effect of such an opening; on the pintle to determine the magnitude of the stresses in these members; and on various members of the superstructure to determine the manner in which the loads were carried down into the pintle.

The strain gage measurements on this structure showed that all stresses in the various members were within safe limits. Such knowledge is an important factor in the design of structures such as this, which are statically indeterminate. This determination was of especial importance at the time of conducting the investigation, inasmuch as another large floating crane of somewhat like construction had only recently collapsed under load while in use on the Panama Canal.

Strength and Efficiency of Electric Welding

The urgent need for ships to transport our men and materials to Europe during the war made it necessary to adopt every means of securing maximum output from the shipyards of this country. The "fabricated" ship, constructed from plate material on which all cutting and drilling had been completed at remote mills before shipment to the yard, saved time at the shipyard under the conditions existing during the war.

A radical suggestion which was never used to the extent which its merits appeared to warrant was the electric welding of the frames and plates of the hull instead of riveting. Autogenous, or fusion, welding has been in use for many years. Most of this work has been done by the use of the gas torch to which oxygen and acetylene are supplied. The weld is formed by fusing together the adjoining edges of the pieces of metal. Material is sometimes added at the same time from a metal rod.

Due to the prohibitive cost of the gases required for oxyacetylene welding and to nonacceptance of welding for certain work by the

insurance companies, the use of welding ship hulls was greatly restricted.

The possibility of so developing electric welding as to permit its being accepted to replace riveting was carefully considered.

In the electric-arc welding process the fusion of the metal is effected by an electric arc formed between a metal rod (or electrode) and the pieces to be joined. Metal from the rod is deposited in the weld.

The welding committee of the Emergency Fleet Corporation was formed to study the matter carefully and to conduct any needed investigations. This Bureau had representatives on the committee and performed much of the laboratory work for determining the properties of the welds, particularly the strength.

In order to obtain definite information upon welds which were being made commercially, a large number of pieces of one-half inch steel plate were welded at different shops using all available types of apparatus. These were known as the "Wirt-Jones" tests and attracted a great deal of attention from engineers and shipbuilders.

The welding data included for each test weld, besides the identification of the operator, the position in which the weld was made, the type of weld, the rate of welding, the type of electrode used (with its diameter and manufacturer), the arc and open-circuit voltage, and the amperage. These data were obtained in the shops where the welds were made. The specimens were machined there and elsewhere. The physical tests were all made at the Bureau of Standards and consisted of tensile, torsional, fatigue, and cold-bending tests.

It was found that all of these except the fatigue tests were consistent. A specimen showing high strength in the tensile test showed high strength in the torsional also. The specimens showing relatively high ductility in the tensile tests showed equivalent ductility in the cold-bend tests.

The fatigue tests were made in three Upton-Lewis machines and by three different engineers. Unfortunately, the results do not appear as consistent as could be wished. Many fatigue experiments should be conducted if reliable data are to be obtained upon this important property of welds. It is believed by many engineers that the failure of welds in service is usually by fatigue and that this property of welds is relatively more important than the fatigue resistance of the material in which the weld is made.

The total number of specimens in this series was over two hundred, and the testing work required most of the time of two engineers for nearly a week.

In addition to the Wirt-Jones tests, this Bureau was at one time making progress reports to the welding committee on 14 investigations planned to give information upon some of the many problems constantly arising in connection with welding work. The number of specimens involved in these investigations varied from 5 to 42.

Due to the satisfactory results obtained from these tests, it was decided that the electric-arc welding process was suitable for ship construction, and the committee formally recommended to the Emergency Fleet Corporation that a merchant ship be designed to utilize welding wherever it could be employed to advantage and that the ship be completed as soon as possible.

The signing of the armistice took place before much progress was made, but some commercial shipyards are now energetically preparing to construct ships in which nearly all the frames and plates for the hull are to be welded into place.

It is estimated that the cost of welding will approximately equal the cost of riveting plates and frames after they have been "laid off" and the rivet holes punched. For welding, however, all this preliminary work is unnecessary, and the plates and angles do not need to be as accurately cut to dimensions. The saving if welding is used is therefore very large, and it is chiefly a saving in labor cost, which under present conditions constitutes a large portion of the total cost.

One result of these extensive investigations was the important conclusion drawn from the results of the Wirt-Jones tests by the chairman of the research subcommittee of the welding committee, that the best physical properties were obtained from those specimens welded with the highest current density in the electrode. Apparently, under this condition, thorough fusion occurred in the weld.

The importance of this discovery, which is generally accepted at present, is very great. The fact that little properly conducted investigational work has been done upon welding processes, and that there are many possible lines for improvement, leads to the conclusion that such work offers great possibilities if properly carried out.

The American Welding Society, an outgrowth of the welding committee, has been formed to encourage welding research work

by coordinating the efforts of industrial, educational, and governmental laboratories. This Bureau is assisting the work of this society in so far as possible.

In an extension of the experimental work to determine the fatigue resistance of welded joints such as would be actually used in ship construction large specimens were made from plates one-half inch thick, 8 inches wide, and 40 inches long.

A fatigue machine driven by a 15-horsepower electric motor was designed and built to subject these specimens to repeated bending stresses, with provision not only for recording the number of cycles of stress required to cause failure, but also for making an autographic record of the stress produced in the welded material for each application.

Investigation of Strength of Chains

The Bureau was called on to make two extensive series of tests of chains in connection with its war activities. The earlier series comprised numerous samples of links for anchor chains and was carried out in cooperation with the chain committee of the Emergency Fleet Corporation. The research was intended especially to determine the value of electric welding in chain manufacturing and the relative efficiencies of cast and forged links.

The anchor-chain links tested included wrought-iron, machine-steel, rolled-shafting steel, and electric-cast steel specimens. Some were cast integral, others were drop-forged, and still others were welded. Certain of the links were prepared with studs and others without. The tests were not extensive enough to warrant general conclusions on the relative values of these different types of links, but they sufficed to furnish considerable comparative data.

Six electric-welded basic open-hearth steel links of 2¼-inch bars showed an average strength of 350 000 pounds. Three links, each drop-forged from 2-inch bars of steels of various manufacture, averaged as follows: Rolled shafting steel, 212 000 pounds; machine steel, 345 000 pounds; and electric steel, 380 000 pounds. Electric-welded links of 2½-inch stock averaged 260 000 pounds strength for chain iron and 280 000 pounds (one test only) for steel. Fracture occurred in all cases at the welds.

An interesting comparison is afforded by the study of the results of tests of six links of cast steel, all of 2-inch diameter stock. Three of these links which had been heat-treated after

casting failed at loads of 326 000, 400 000, and 365 000 pounds, respectively. A microscopic study of the fractures showed the steel to possess a very good structure. Two cast electric-steel links averaged 440 000 pounds strength, and an accompanying link made from basic open-hearth steel failed at 370 000 pounds. This last open-hearth had also been heat-treated after casting, and showed six times as great elongation as did the two electric-steel links. All anchor-chain links tested were about 12 inches long over all.

This series of static laboratory tests demonstrated the relative superiority of cast-steel links. Dynamic tests made elsewhere with the cooperation of the Bureau also served to establish the relatively greater desirability of a steel link than of a wrought-iron link. Service tests by the Navy Department also contributed to the establishing of the efficiency of cast chain which received the approval of Lloyd's Register of Shipping.

In the process of reorganization of the Army, by which the purchase of various supplies was concentrated in suitable Army branches under the general direction of the Purchase, Storage, and Traffic Division the procurement of chain was assigned to the Engineer Corps. The Bureau was represented, together with other Government departments on the committee on chain.

The Bureau made extensive tests of harness, vehicle, towing, sash, anchor, and other types of chain with straight links, twisted links, plain stud, and other links in its cooperation with the War Department standardization committee. It also tested harness, clip-grab, box, and barrel hooks in the course of this investigation. The test data obtained here, combined with that obtained in commercial tests, furnished the basis for the formulation of chain specifications. Standard War Department specifications for chain, together with much other data, including a list of manufacturers, have been published in the War Department Catalogue No. 5.

Wheels, Investigation of, Artillery, Truck, and Airplane

This subject will be found under the above heading in another part of this report.

Metal Construction for Airplanes

A description of the work carried out on this subject will be found under "Aircraft Construction."

NATURAL-GAS INVESTIGATIONS

Among the war activities of the Bureau may be mentioned the work on the various problems presented by the natural-gas industry. The increased demands upon all industries brought about through the war and the unusually severe winter of 1917–18 combined to cause a complete breakdown of this industry in particular localities. Calls for assistance came from several such places and were given the attention of the gas engineering section of the Bureau.

Beginning of Natural-Gas Work

The first of these calls came in the early winter from Cleveland, Ohio, where a shortage of natural gas was threatening to cause considerable suffering. The Bureau had in 1916 made a study of the city's testing facilities, and in October, 1917, was asked for further assistance along that line, and also for help in dealing with the natural-gas problem in that locality. The survey of local conditions made by the Bureau's representative in January, 1918, showed that the situation was being handled as well as could be expected locally, but that the problem demanded more than merely local treatment. Recognition of this fact led the Bureau to consider an extensive investigation of the needs of the industry.

On December 31, 1917, Louisville, Ky., requested the assistance of the Bureau in dealing with its shortage of natural gas, since the Bureau in 1913 had assisted in framing the Louisville gas ordinance. As a result of this request a representative of the Bureau was sent to Louisville in the latter part of January, 1918, and a brief preliminary report on the situation was rendered on January 28 with the recommendation, similar to that made in the Cleveland report, that the available supply of gas be rationed so as to secure its most equitable distribution. The need for an extensive study of the natural-gas situation was reemphasized by the Bureau's experience in Louisville.

General Natural-Gas Investigation

Late in February, 1918, the Bureau definitely decided to make the extensive investigation that was so urgently needed. It was proposed to make a survey of the production, transmission, and consumption of natural gas with a view to eliminating waste in its production and consumption, to securing a fairer distribution between communities of the available supplies, and to securing a more equitable division of the supply between members of the same

community. The wasteful consumption of natural gas in the manufacture of carbon black, brick, etc., has shortened the life of the industry by many years, and the use of natural gas for other industrial purposes, such as the manufacture of steel, is undoubtedly a case of putting a natural resource to one of its least important uses. The interstate transportation of natural gas gives rise to many complications, not the least of which is the instinctive desire of a producing State to keep its gas at home. Thus West Virginia dislikes to see two-thirds of its production transported to Pennsylvania, Ohio, Kentucky, even to Indiana, while its own citizens experience a shortage. In one locality 8 per cent of the consumers use half of the available gas, and thereby cause others who need it to go without. These are some of the problems to the solution of which the Bureau was intended to contribute.

Particular attention was to be given to the Louisville situation as presenting in concentrated form the various aspects of the natural-gas problem, with the expectation of later applying to other localities the principles developed here. The Bureau was interested principally in the public utility or service aspects of the work, while it asked for and secured the cooperation of the United States Geological Survey and of the Bureau of Mines in working up the scientific and engineering aspects of the problem. One of the Bureau's consulting engineers was placed in charge of the field investigation.

An elaborate report entitled "Fundamental Principles of Natural-Gas Production, Service, and Conservation, with Special Reference to the Natural-Gas Situation at Louisville, Ky.," was prepared and presented on August 20. As indicated by the title, this report explained the methods of natural-gas production, transmission, and local distribution and utilization, with a useful discussion of the vital problem of conservation. A fifth part contained much useful information on the Louisville situation. The Bureau recognized the considerable merit of this work, but did not think it advisable to publish it without certain modifications of the treatment. It later appeared as No. 7 of the "Mineral Industries of the United States" series of the National Museum, and no doubt is finding a wide circulation among those interested in the natural-gas industry and in the conservation of our natural resources.

Relation to the United States Fuel Administration

However, the Louisville case still remained unsettled and demanded attention. In September, 1918, a representative of the

Bureau went to Kentucky and, with the assistance of an expert, made a field study of certain gas territory in eastern Kentucky which might be used to add to Louisville's supply. The report rendered by this expert has been much in demand. The Bureau's representative then visited Louisville in hopes of effecting a solution of the problem, which was becoming daily more aggravated. The local situation rendered the Bureau's recommendations as to rationing and the manufacture of gas impracticable. Appeal was made by the local company to the United States Fuel Administration, and a rationing order similar to those issued for several other localities was issued. Although the Bureau did not actively participate in the hearing of this case before the Fuel Administration, it nevertheless is a source of gratification to know that the action of the Fuel Administration was exactly in line with the Bureau's recommendations to the city.

The increasing activity of the natural-gas division of the Fuel Administration rendered it unnecessary for the Bureau to carry its investigation further. With the lapse in power of this war bureau, it is not unlikely that the Bureau will again render such assistance as is within its power to any localities which may have natural-gas utility problems to solve.

Technical Results

Certain features stand out clearly as the result of the Bureau's study of the natural-gas industry. The principal one is that there can be no adequate solution of the natural-gas problem on anything less than a national scale. The industry has developed and spread out in an entirely aimless fashion until now there exists an overdeveloped demand on what is, after all, a strictly limited natural resource. Local selfishness results in mad scrambling to secure all the gas possible, regardless of the rights or needs of other communities. To reconcile these conflicting interests and to formulate some principles which shall control the future use of natural gas calls for treatment by some national body with power to compel observance of its orders. Unfortunately, no such body exists during peace times.

Aside from rationing between communities and States, there is need for continued rationing within each locality. This has been accomplished quite generally in some States during the war and should be extended and rendered a permanent part of our national program. Industrial use of natural gas should be severely limited or largely eliminated, and its use for house-heating purposes should be actively discouraged.

In view of the fact that the wisest possible treatment of this natural resource can only delay for a few years (in most localities) the time when the supply will be so nearly exhausted as to make it unprofitable to continue either to carry the gas long distances or to sell it at the present relatively low rates, it is not unlikely that the Bureau will be called upon by numerous cities to assist them in framing ordinances governing the manufacture of gas and its sale, either straight or mixed in some degree with natural gas. The Bureau has rendered some such assistance to Sandusky, Ohio. Mention might also be made in closing of the assistance which the Bureau rendered the State of Oklahoma in framing its natural-gas service standards. The natural gas problem is by no means solved; in fact, as the years go on, it is certain to become much more acute. The experience which the Bureau has accumulated during the period of the war will prove of great future value.

While by no means the most important work of the gas engineering section during the war, this work on natural gas has afforded a measure of relief to afflicted communities and was of assistance in forwarding the Nation's war program.

Investigation of Town-Border Natural-Gas Meters

In connection with the above-described efforts of the Bureau to aid in the conservation of the natural-gas resources of this country, the United States Fuel Administration requested the Bureau to determine the accuracy with which gas was being measured through the meters established at the town borders of a large number of cities and towns in Kansas and Missouri. Accordingly, the Bureau sent into these States members of its staff who, during the months of November and December, 1918, and January, 1919, tested 103 of these large meters. Of these 56 were positive meters, 33 orifice meters, 2 pilot-tube meters, and 12 proportional meters. In addition to the actual testing of the meters, the average conditions of temperature and pressure at which the gas was measured were investigated.

On the basis of the Bureau's work it has been estimated that during 1918 several million dollars' worth of gas was lost by leakage in the distributing plants receiving gas through the meters tested.

Recovery of Helium from Natural Gas

Another line of research conducted by the Bureau on natural gas was the production of pure methane for the determination

of its physical constants. Helium was needed for the inflation of balloons, and the only commercial source of helium was the natural gas found in certain localities. By far the largest constituent of natural gas is methane, and in order to obtain the helium, it was necessary to remove the methane. It was decided that the best method of accomplishing this was by cooling the natural gas until the methane was liquefied and the helium alone remained gaseous. It was necesssry to accurately determine the physical constants of methane in order to properly design the necessary refrigerating machinery. Methane was produced in large amounts by three different methods. The first method consisted in the production of the gas by the Grignard reaction; methyl magnesium iodide was produced by the reaction between magnesium and methyl iodide, and this was then decomposed with water, liberating the methane; the methane was purified by chemical means, liquefied, and then further purified by fractional distillation. Considerable methane was also prepared by the separation and purification of the methane contained in a sample of natural gas rich in methane; and a third sample was prepared from aluminum carbide. The samples thus prepared were turned over to the heat division of the Bureau for the determination of the physical constants of methane. These values were communicated to the Bureau of Mines and were used in the designing of machinery and also in checking up the operation of the plant used for the production of methane.

OPTICAL GLASS AND OPTICAL INSTRUMENTS

The Production and Testing of Optical Glass

Work on the production of optical glass was begun during the year 1914–15. The first difficulty experienced was in securing satisfactory pot material able to resist the corrosive effect of these glasses.. This was found in a kaolin-clay mixture which proved very satisfactory, and the composition of which was communicated to several glass plants.

The early experiments in the manufacture of optical glass were conducted with pots holding about 30 pounds of glass. The quality of the glass produced under various conditions of heating and cooling the melts was investigated, and the effect of stirring studied in pots of this size until the winter of 1916–17, when a larger furnace, holding a 1000-pound pot, was built and operated. A furnace of this type is shown in Fig. 20. In this furnace the first large melt of commercial borosilicate glass was produced. At

the same time the composition of the different glasses was studied by means of small melts, and the results of this work were continually compared with such information from foreign sources as was available.

The subject of the chemical compositions of the optical glasses had been practically mastered when war was declared. At this time a conference was held with representatives of the geophysical laboratory of the Carnegie Institution, and the information collected by the Bureau was made available to them. Three representatives of the geophysical laboratory were then stationed at the Pittsburgh branch of the Bureau of Standards and were given an opportunity of observing the operations of glass making as there carried on. The same information was made available to three glass manufacturers. There was at all times close cooperation between the technical men of these plants and the scientific staff of this Bureau, in connection with both the obtaining of suitable pots and the making of optical glass.

Simultaneously with the work of producing optical glass of high quality improved pots were developed, and the final product, the porcelain pot, has given excellent satisfaction. In the construction of this type of pot use is made of the waste bisque of white-ware potteries, thus affording a cheap and reliable source of calcine, accompanied by the saving of material heretofore wasted. Furthermore, a procedure for casting pots was developed in every detail, a process which does away with the usual laborious hand building, and results in pots of a superior structure at a considerably lower cost. This process is an original contribution to the technique of glass manufacture and is bound to result in far-reaching changes in the production of glass-house refractories. Five such pot-making equipments have been designed and the drawings furnished to glass plants.

At one of the optical glass plants a system of rapid inspection of optical glass was initiated by a representative of the Bureau, employing the immersion of the glass in carbon bisulphide and gasoline. This testing system has been developed by the Bureau's staff and was used for some time in testing the output of the Pittsburgh plant. The system is likewise being used at a number of factories. There is a large saving in labor, as the work of polishing the slabs for examination is thereby eliminated. In addition, accessory tests have been devised which have proved very useful, and the polishing process has been developed from an unsatisfactory state to a high degree of perfection. The

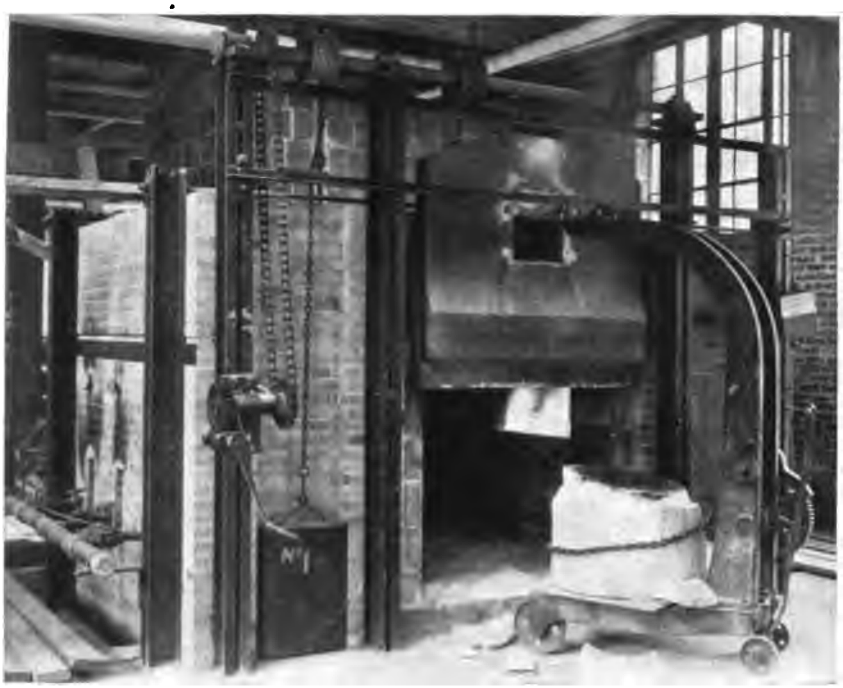

FIG. 20.—*Furnace for making optical glass*

The pot in which the various ingredients are melted is shown on the truck and is partially broken away to show the solidified glass. Before the war all the optical glass used in this country was produced by a few firms in Europe. Through the Bureau's investigations improved manufacturing processes have been developed, and the industry securely established in the United States

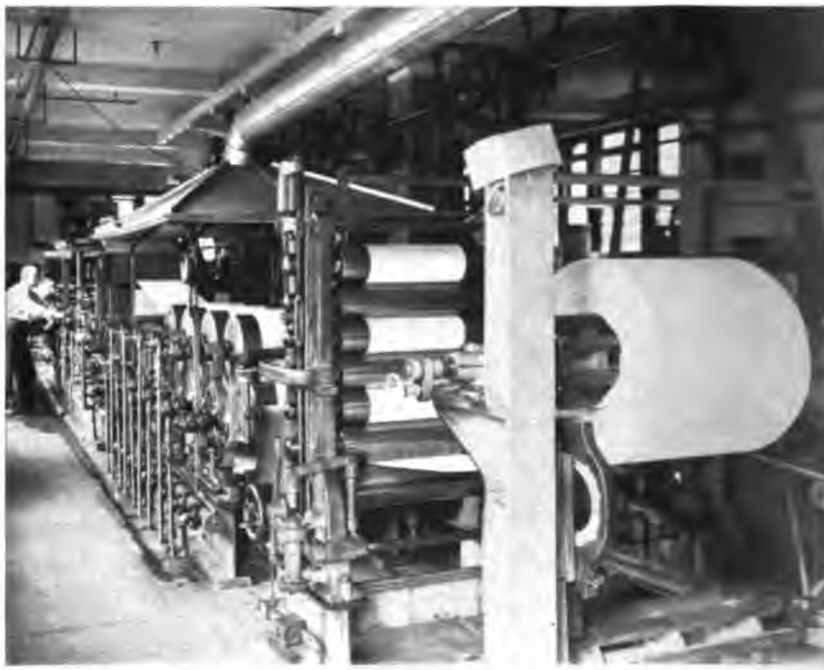

FIG. 21.—*Experimental paper machine*

Paper entered into a great deal of the construction work carried on during the war. To investigate new manufacturing processes, a complete paper mill is operated by the Bureau. The machinery is identical, except in size, with that employed in commercial plants

testing methods worked out by the Bureau have given general satisfaction.

The Pittsburgh laboratory of the Bureau, operating eight single-pot furnaces, worked out in complete detail the melting operations involved in the production of the principal optical glasses, the most suitable compositions, the processes of pressing blanks and of annealing. The yields of good glass produced at this plant were very satisfactory, and were probably higher than those obtained at commercial plants. In this manner the Government secured authentic and accurate information concerning the whole problem of optical-glass making, which is available to the authorities concerned and to the general public.

More recently the Bureau experimented with the production of dense barium crown glass of the type used for certain photographic lenses. This glass is more difficult to produce than the ordinary types, and the results were not entirely satisfactory. However, glass of this type of a fair grade was produced and submitted to the leading photographic lens manufacturers of the country for trial. These trials have shown that lenses made of the glass gave satisfactory performance. Demands for the glass necessitate further production, which will undoubtedly give larger yields of improved quality as well as proper control of the optical constants.

Testing and Design of Military Optical Instruments

All the melts of optical glass made at the Pittsburgh laboratory of the Bureau, about 300 in number, were submitted in samples to the optical instruments section for the determination of the refractive indices, dispersion, and transmission factor of the glass composing the melt.

The refractive indices and dispersion were at first determined on a spectrometer. This method involved the expense and delay incident to the making of a small and accurately finished prism of the glass under examination. It was subsequently found far easier to determine these values on a Pulfrich refractometer, which requires only a small slip of glass, about 10 by 20 by 2 mm in size, polished on one face and one end. The indices were determined for three or four spectral lines in the fourth decimal place. The dispersions, using a differential method, were found to five decimal places.

The transmission factors were determined on a Martens photometer. By the use of an auxiliary table the loss of light in transmission can be quickly computed in per cent per centimeter.

In addition to performing this work on all Bureau melts, assistance of the same sort was given to a number of manufacturers of optical glass. One of these companies did not supply any considerable amount of glass to the American Government, but entered into a contract with the Italian Government to supply optical glass of which that country was in urgent need.

A very important point in the inspection and utilization of optical glass is found in the subject of striæ. The best optical glass should be entirely free from striæ; under the stress of war needs, glass of slightly lower quality was occasionally used in certain parts of binoculars and other military instruments. The Bureau has conducted an extended investigation on the subject of striæ and their effect on the performance of the completed instrument. In some cases it has been found that where the two barrels are affected to unequal extents by striæ, the performance of the striated barrel is at least as good as the unstriated one. Many other factors than the existence of striæ enter into the satisfactory performance of an instrument of this type. In general, it may be said that striæ, if faint or few in number, are not very injurious in the objective of binoculars, but are considerably more so in the prisms and eye lenses.

The Bureau has also frequently conferred and advised with military and naval authorities on the subject of specifications for optical glass.

While many special types of military instruments were subjected to test by the Bureau, to be mentioned in detail later, the major portion of the work was centered upon the testing of binoculars. The Bureau was requested to perform check inspection on one out of every hundred binoculars produced for the Signal Corps. Special apparatus was designed for the rapid testing of field glasses (to be described in greater detail under the title "Devices Perfected"), and these methods were adopted by the Signal Corps, the work being under the supervision of a member of the optical-instrument section of the Bureau. Occasional tests were also conducted on instruments of this type for other branches of the military forces. The table below shows the number of binoculars tested at the Bureau, by months, and serves also to indicate the rise in production:

Tested before July 1, 1918	315
Tested during July, 1918	78
Tested during August, 1918	51
Tested during September, 1918	97

Tested during October, 1918	113
Tested during November, 1918	174
Tested during December, 1918	80
Total to Jan. 1, 1919	908
Tested for Navy Department; Crown Optical Co. glasses rejected by British Government, tested thoroughly for striæ	120
Tested for Shipping Board, Emergency Fleet Corporation, acceptance tests only; Galilean type	1001

The Bureau was called upon by the various branches of the service to make special tests of photographic lenses, although most of the testing of such lenses has been carried out under Army supervision at the experimental laboratory of the manufacturer. The General Engineer Depot of the War Department, and the Geological Survey in particular, made use of the Bureau's facilities for such testing.

The facilities of the Bureau were also used by the Signal Corps to test the speed of their camera shutters. The actual work, however, was done by enlisted men detailed to the Bureau by this branch of the service.

The Bureau was called upon to make tests of various sorts on a wide variety of optical instruments for military purposes. Periscopes, small range finders, gun sights for both Army and Navy, bomb sights, aviators' goggles, and other instruments were brought to the Bureau for test and for conference. In some cases the work done by the Bureau has been comprehensive, in others the assistance rendered has been mainly in the nature of advice following a short discussion of the construction of the instrument. In the first class may be mentioned the tank-gun sight, the 37 mm gun sight, the panoramic machine-gun sight, a periscopic alidade, and binoculars from companies who were commencing to manufacture these instruments. In the case of the tank-gun sight, the inspection division of the Ordnance Department was in almost constant consultation with the Bureau, and the laboratory facilities were used freely for making the tests necessary for putting the instrument on a production basis. The range scale for this instrument was computed at the Bureau, and a representative of the optical-instrument section made a special trip to Boston in connection with the production of this instrument.

A representative of the inspection division of the Ordnance Department was detailed to the Bureau and made use of the laboratory facilities for building the apparatus necessary to test the optics of the 37 mm gun sight.

A conference on the specification for the panoramic sight for machine guns was held at the Bureau on July 15, 1918, and from then up to the time of the signing of the armistice the engineering division of the Ordnance Department was in frequent consultation with the Bureau with reference to the specifications and performance of this instrument.

A periscopic alidade was sent by the Expeditionary Forces to the General Engineer Depot with the request that the instrument be copied and supplied to the American Army. The sample was turned over to the Bureau, and the instrument taken apart and various parts measured. The General Engineer Depot was then furnished with all the data necessary for the construction of a similar instrument. From the data supplied to the Engineer Depot a blue print of the optical parts was prepared and turned over to an instrument manufacturer. A sample American-made instrument was returned to the Bureau of Standards, and this instrument, after a few minor changes, was approved.

A certain company undertook for the Signal Corps the manufacture of binoculars and worked in connection with this Bureau. They had some difficulty at first in getting the optical parts of the binocular properly placed in the instruments and referred some of their troubles to the Bureau, which was able to be of assistance in getting this company on a production basis.

In consultation with the Bureau another firm embarked on the manufacture of a new type of binocular in which the machine work is largely replaced by pressed metal parts. This company did not reach the production stage during the war, but there is promise in their work, and there is a more than fair indication that they will be able to produce in the very near future a good binocular at a much lower labor cost than is usual at the present time.

The supply of sextant mirrors of a satisfactory degree of parallelism between the two surfaces was inadequate, and great difficulty was experienced in getting workmen to turn out such plates. A member of the Bureau's staff, detailed to one of the glass-making plants worked out a satisfactory method of polishing these mirrors, and they are now being produced in quantities and are apparently of a satisfactory grade.

In connection with the work of inspecting binoculars for the Signal Corps, and in addition to the detail of a man to assist the Signal Corps in this work, there was held at the Bureau during the month of October, 1918, a short course for the instruction of inspectors of binoculars. The inspectors so trained were sent

out to the various factories and were engaged in the work of performing the acceptance tests on binoculars. There were nine inspectors detailed for this work.

For the Ordnance Department of the Army a modification was made in the Aldis unit sight by the insertion of a lens-shaped bubble glass to adapt the instrument for use as a bomb sight. The device has proved very efficient for the purpose.

For the same department a projection-aiming device was constructed for nightwork with machine guns.

Binocular Testing

Aside from the assistance given by the Bureau in design or construction of optical instruments, described earlier in this report, the devices perfected and procedure followed in binocular testing merit further description.

Tests on the following elements of performance or construction were called for: (1) Resolution; (2) field of view; (3) parallelism of axes; (4) magnification; (5) exit pupil; (6) transmission; (7) correctness of mil scale; and (8) star test.

To make all these tests on a large number of binoculars would be a very onerous task. A set of appliances was accordingly developed at the Bureau by which these various tests can be readily made. In fact, this testing has been brought to the stage where the time consumed in making the actual tests is considerably less than the clerical labor of recording and reporting the tests and the manual labor of packing and shipping the tested binoculars. The apparatus is not elaborate, does not require a great amount of machine work, and the results are obtained well within the accuracy required. The methods of making these tests, the tolerances to which the tests were made, and the apparatus used will be taken up in order.

The resolving power of the human eye is slightly less than one minute of arc. An instrument of magnification M should be capable of resolving or separating two objects separated by $1/M \times 1'$. In the case of a 6-power binocular the limit of resolution should be less than $1/6 \times 1' = 10''$. A resolution of $6''$ will be very good, $10''$ passing. Greater than $10''$ not acceptable. This value was determined by means of a resolution chart. The resolution screen was drawn on drawing paper on a large scale, and reduced photographically so that the distances between the lines would have values of from $3''$ to $10''$ when viewed at the chosen distance, which in this case was 60 feet. A small auxiliary telescope was placed so as to look through the binocular at the

resolution screen. The screen itself was lighted up by a frosted light bulb in an ordinary projection lantern with lens removed; a ground-glass diffusing screen was placed where the slide would normally come, and the resolution screen was placed about 3 inches from the ground-glass screen. This furnished a satisfactory source, sufficiently bright for the purpose. By making readings on both the vertical and horizontal lines of the screen, the effects of astigmatism were observed.

The auxiliary small telescope was found advantageous on a number of counts, although some opposition developed among manufacturers to its use in testing, their contention being, in effect, that its use showed defects in binoculars which could not be detected by ordinary visual and service tests. Common sense must, of course, be employed in collating much more rigorous tests with service requirements. The use of the small telescope has the great advantage that it enables resolution tests to be made without fatigue and strain. In direct tests of resolution without the aid of the extra magnification furnished by the telescope, the eye must work at nearly the limit of its resolving power, soon producing fatigue and rendering the results less trustworthy.

The field of view was tested by means of a scale at a distance of 15 feet. The scale was so drawn as to allow for the slight correction necessary because of the focusing of the binocular on an object close at hand, so that the angular field of view could be read directly from the scale. The binoculars tested had a field of 8°, which occasionally ran as low as 7° 40′; no definite tolerance was required in these tests.

An important test is that for parallelism of the axes. If the axes of the barrels of an instrument of binocular type are not parallel, the eye will be put to undue accommodation strain, and, if the error is large, it will be impossible to accommodate sufficiently to prevent the seeing of two images. The amount by which the axes may depart from perfect parallelism depends upon the magnification of the instrument. It can be shown that the angle to which the eye has to accommodate itself to allow for such lack of parallelism is $(m-1)$ times the actual angle between the axes, where m is the magnification. For the six-power binoculars tested the tolerances set by the Signal Corps have been six minutes in the horizontal plane and three minutes in the vertical plane. The results of these tests would seem to indicate that manufacturers have no difficulty in keeping well within these limits.

The apparatus used for the parallelism tests was modeled from a description of similar apparatus used by the French Government, and an apparatus working on the same principle has been described by Drysdale in the 1905 report of the Optical Convention. It consists of two reticles mounted side by side, the distance between them being that between the two barrels of the binocular, a ground-glass bulb for illuminating the reticles, a means for holding the binocular in position, and a suitable arrangement of lenses and mirrors with a screen on which the images of the reticles are projected. The operation is as follows: The ground-glass bulb gives a diffuse illumination on the reticles, and the light then passes through two collimator lenses. From these the light enters the barrels of the binocular. A 7-inch collecting lens takes the light from both barrels and projects the images of the reticles upon a screen through the medium of two mirrors. The superposed reticles, with no binocular in position will produce an image upon the screen. The same is true with the binocular in place, except that the image will be of smaller size. Lack of parallelism will show in a displacement of the image of one reticle in reference to the other. The reticle oblong is made of such size that its image on the screen will be 6 feet long by 3 feet high, when a 6-power binocular is under test, thus enabling the variation from parallelism to be estimated directly from an inspection of the reticle image.

The apparatus used for testing the magnification is practically the same as that used for testing the parallelism, except that but one collimator is necessary and the large 7-inch lens can be replaced by a smaller one. A pair of fine lines is ruled on a strip of ground glass, which is placed at the focus of the collimating lens. Introducing the binocular, an image of these two lines is formed on a ground-glass screen, as magnified by the binocular. The magnification may thus be read off directly to 0.1, which is sufficient for the purpose and is the tolerance as set by the Signal Corps.

The exit pupil, or Ramsden circle, should be as large as the eye pupil of the observer if full advantage is to be taken of the illumination of the object observed through the telescope. For the quick measurement of the exit pupil a projection system is used at the Bureau. An electric lamp illuminates the telescope objective and a short-focus lens, *l*, projects the image of the pupil upon the screen at *s*. On the screen there is a movable scale calibrated to read the pupilary diameter directly in millimeters. The lens

l and the screen s remain fixed to maintain a constant magnification, the telescope being shifted to get the pupil in sharp focus on the screen.

The transmission is defined as the percentage of light which passes through the apparatus in terms of that incident upon the objective. This percentage will vary in different instruments in accordance with the number of separate surfaces in the optical system, thickness of lenses and prisms, and transparency of the glass used. In a Galilean type binocular the transmission should reach 80 per cent. A good prism type binocular should reach 50 per cent in the barrel which has no mil scale and 40 per cent in the one with the scale; but these values are not often attained.

The transmissions were measured on a Martens photometer. A set of prisms was arranged to do away with the necessity of using a comparison light. This was found to be a very satisfactory arrangement, as it obviates the necessity of continually checking the zero reading of the instrument and avoids the effect due to fluctuations in the potential of the current used in the lighting system.

A great saving of time was achieved by providing the photometer with a special divided head by which the percentage of light transmitted could be read off directly. This procedure, together with the prisms mentioned above, made the determination of the transmission factors a very simple matter.

In order to make what is known as the "star test," two small apertures of about 0.7 and 1 mm diameter were provided in the resolution screen. The appearance of these "star images" as observed through the small telescope and the binocular in the resolution test frequently affords data of value as to the general performance of the instrument. The faults thus determined come generally under the head of "flare," "color," and "scattered light." No definite rules can be laid down for acceptance or rejection under this test. Decision as to the performance of the instrument must be based on judgment and experience and a thorough comprehension of service conditions.

Mil Scales

The mil scale consists of an auxiliary range-finding reticle which is placed in the eyepiece of the military binocular.

Fine vertical and horizontal lines are ruled on the glass reticle at definite intervals so that it is possible to make comparisons and range determinations at the same instant one may happen to

discover an object or target. The scale posesses the further advantage of enabling the artillery to point at an invisible or indefinite target by aiming at some conspicuous object which may be taken as a reference point on the mil scale.

The Signal Corps requested the Navy Department to construct in its optical shop large quantities of binoculars equipped with these scales. Difficulty was experienced in producing them, and the Bureau was called upon to assist, and in a few days succeeded in correcting the apparatus so that quantity production became possible.

Early in 1918 the Bureau discovered that the scales supplied by one of the largest commercial manufacturers contained serious errors. This discovery was promptly communicated to the Signal Corps and to the manufacturer. The Bureau was authorized by the Signal Corps to confer with the manufacturer on this point and to see that proper corrections were made. After the matter had been gone over thoroughly, the corrections were made and no further troubles were experienced.

ORDNANCE

Hardness of Brass Cartridge Cases

This subject is treated under the heading "Metallurgical Investigations."

Machine-Gun Erosion

A systematic study of this subject is being made from the metallurgical point of view, including the preparation of a considerable number of special tests, determination of the interesting physical properties, and the ballistic tests, which last are being conducted by the Ordnance Department itself.

Copper Crusher Gages

At the request of the Society of American Manufacturers of Small Arms and Ammunition and of the Ordnance Department of the Army, the Bureau has been actively engaged in the preparation of specifications for copper crusher gages for testing ammunition and standardizing the method of use. A considerable amount of work has also been done on the characteristics of the copper crusher cylinders, particularly as related to their properties under various conditions of annealing and as dependent upon their conditions of precompression, and includes a study of the resulting errors. Several conferences have been held, and it is expected shortly to close this subject.

Defects of Shrapnel Steel

This subject is treated under "Metallurgical Investigations."

Light Armor Plate

This subject is treated under the heading "Metallurgical Investigations."

Synchronizing Devices for Airplane Guns

This subject is treated under "Aircraft, Miscellaneous."

Removing Metal Fouling from Rifle Barrels

This subject is treated under "Chemical Investigations, Miscellaneous."

Munitions Gages

A complete description of this work is found under the heading "Precision Gages."

Airplane-Gun Mount

Airplanes designed for fighting were provided with flexible mounts for the machine guns and a safety belt for the gunner. It was important to determine whether both the mount and belt were sufficiently strong for the purpose intended. In order to subject these to tests approximating actual conditions, special equipment had to be provided for attachment to one of the Bureau's testing machines. Through the use of this special equipment the mount could be tested in an inclined position, thus approximating the probable average flying condition. The Bureau carried out quite extensive development work along this line and after a satisfactory form of construction was established performed a number of acceptance tests.

Powder-Shipping Containers

Some of the powder containers tested were of fiber and others were of sheet metal. The fiber containers were subjected to the following tests: Internal air pressure, submergence, Mullen or bursting strength, and tensible strength tests of the cardboard of the wall. The load required to pull off the crimped-on container ends was also determined in several instances, as well as the effect of the submergence test on the metal of the ends. All metal containers were tested by submergence, air pressure, and in impact by tipping over a container loaded with sand onto the floor and also by dropping a weight on it from increasing heights until failure occurred. As was the case very frequently with all materials, the Bureau was here called on to pass judgment upon

radical modifications of current design in powder containers. Such advice, which was more frequently furnished orally than by correspondence, served as the basis for the Ordnance Department's action in the standardization of their powder-container design.

Semisteel Shells

Extensive tests were made in an investigation of the possibility of using semisteel or processed cast iron in lieu of steel for shells. Initial experiments of American manufacturers with the use of semisteel were unsuccessful, although French factories were then turning out satisfactory shells of this material. Careful comparative studies were made of samples of American and French manufacture, respectively, which included physical, chemical, and microscopic examinations. The physical tests conducted included tensile, compressive, and transverse strengths, hardness and impact determinations. Suitable criterions were established which served as acceptance bases for the purchase of shells. Quality production of satisfactory semisteel shells had been begun before the signing of the armistice.

Copper Rotating Bands for Shells

Considerable trouble was experienced by the Ordnance Department with the copper rotating bands on shells. It was found that some of the bands when formed to the required size and shape were so brittle that they failed in service by breaking. Other bands were so soft that they filled the rifling on the inside of the gun barrel with copper and caused jamming of the shells. The possibilities for the use of arsenical copper in the manufacture of rotating bands were investigated, and numerous suggestions for improving their quality were furnished the Army.

Gun Barrel with Gored Rifling

One of the special problems investigated was the cause of failure of a 75 mm gun in which a gash had been torn in the rifling when the gun was fired. It was important to discover whether this failure had been due to some imperfection in the metal out of which the gun had been constructed or because of an imperfect shell. In order to do this the gun was tested coincidentally with a 155 mm howitzer which had proved satisfactory in service. The gun with the flaw performed as satisfactorily in the physical tests and microscopic examination as did the other, which appeared to indicate that the flaw resulted from a faulty shell and not from any defect in the manufacture of the gun itself.

French and American Trench Mortars

An extensive comparative investigation was conducted of the relative properties of 240 mm trench mortars of French and American manufacture. The study included physical, chemical, and metallographic examinations. The French steel was found to have a finer and more uniform texture with over 10 per cent greater strength than the American material. This superiority of the French material appeared to be the result of better heat treatment, as the foreign steel had a lower carbon and manganese content, which would normally indicate lower strength.

Railway Mount Recoil Piston Rods

A number of 6 and 8 inch diameter recoil piston rods for railway mount howitzers were prooftested by the Bureau to loads twic those brought upon them in firing. These rods necessitated th use of approximately the maximum load which can be applie with the large Emery hydraulic machine, namely, 1 150 000 pound in tension. The elongations in a 5 or 6 foot gage length wer obtained as successive loads were applied and stress strain curve were plotted for the rods.

This is one of the few laboratories in the country which i equipped for applying large tensile loads to specimens of grea length.

Wheels, Investigation of Artillery, Truck, and Airplane

This subject is described under the above heading in anothe part of the report.

Magnetic Analysis of Rifle-Barrel Steel

This is treated in the section on "Magnetic Investigations."

PAPER

Wall and Plaster Board

The use of wall board and plaster board as a building materia for the construction of military cantonments, Government war houses, office buildings, and similar structures was developed to great extent during the war. Wall board is a general term cover ing those types of building material which are used as a sub stitute for wood lath and plaster in partitions and for sheathin on the inside walls of buildings. The construction of the vas number of Government buildings demanded in the prosecution o the war required the use of a material that could be quickl erected, having a low cost as well as adequate supply. Thi necessity was met by the use of over 100 000 000 square feet of wa board.

Wall boards are made of paper, built up of one or more layers or plies that are cemented together with a binding agent such as silicate of soda (water glass) or other adhesive. Plaster board is made of three-ply material. The inner ply is made of hydrated plaster of paris or gypsum, while the two outer plies are made of a special paper. The finished boards are of thicknesses of three-sixteenths, one-fourth, and three-eighths of an inch.

The term "plaster board" is applied to that type of wall covering that is made of two layers of a special paper with fire-retarding properties superior to ordinary wood lath and plaster and far superior to the all-paper wall board. The strength of this material together with its fire-retarding properties and other qualities, makes it an excellent building material and one that will undoubtedly come into more extended use as its properties and usefulness become more generally known.

The term "wall board" applies to only that type of wall covering that is made entirely of old-paper stock, ground wood pulp, or other paper-making fibers.

Through the War Department the Bureau was requested to assist in the preparation of specifications and methods of testing to determine those qualities desired. Special methods for testing this wall board had to be devised in order to duplicate as nearly as possible service conditions. Samples of all the commercial grades were secured and tested and their relative suitability determined. As the War Department had already used great quantities of this material and was contemplating using much more of it, the need of complete data of the service of this type of building material could not be overestimated. The actual service rendered by this wall board was investigated at various cantonments and in buildings lined with wall board and plaster board which had been erected over a year. The result of this general investigational work has been to greatly improve the quality of the wall and plaster boards used by the Government. These good results have been made possible largely by the hearty cooperation of several of the large manufacturers.

In order that further information might be obtained as to the behavior of these boards under service conditions, a questionnaire was sent to most of the military cantonments. For temporary structures fiber wall board was preferred merely because it was considered quicker and cheaper to erect and because of its greater salvage possibilities. Plaster board was preferred for permanent construction (that is, over five years) because it was

considered less subject to changes in temperature and because it makes a warmer building. For hospital use plaster board was preferred because of its greater resistivity to fire and moisture. In general, it may be said that wherever quality and performance were considered, the plaster board was to be preferred.

Paper as a Substitute for Linen in Airplane Construction

An original investigation was undertaken in the summer of 1917 to determine what materials were necessary to produce an exceedingly strong paper which could be substituted for woven fabrics in airplane coverings. In preliminary tests a mixture of jute and manila rope was found as most promising and had the advantage of being a material which could be purchased in reasonably large supplies throughout the United States. The investigation was divided into two distinct classes: first, the production of a sheet of strong paper, and, second, the investigation of methods for making it waterproof and fire resistant.

A series of runs made on the Bureau's experimental paper machine, shown in Fig. 21, indicated that a paper from the rope stock, comparing favorably in strength with textiles, could be produced. The preliminary experiments demonstrated the limiting factors in cooking, beating, and machine treatment, and made possible definite standard methods which were adaptable to practice anywhere, making reproduction of the sheet possible. The result of the preliminary investigation was the production by the paper section of a paper of quality equal to the samples submitted and of such character that it could be manufactured in widths up to 144 inches continuously on a commercial-paper machine. The survey also showed that there was a reasonable supply of the necessary material available in this country. The method of treatment was long and the cost of the paper would be high, but presumably it could be procured at a price lower than woven cotton or linen fabric. The economic conditions were not investigated further than to determine that a supply was easily available.

After having made the paper, attempts were made to develop a method of laminating two or more sheets together to produce a single sheet, having a weight of 6 ounces to a square yard, since, as manufactured, the sheets weigh about 1½ ounces per square yard. It was the idea of the paper section that a glue or adhesive could be developed which would not only securely fasten the sheets together, but would also render them waterproof and to a certain extent fireproof.

The idea of discovering a material of this type was worked on, and experiments were made with the following agents: Switzer's reagent, glue, casein and blood mixed, sodium silicate, formaldehyde glue, bichromate glue, common glue, oil emulsion, zinc chloride, sani dry, and halowax. No satisfactory results were obtained in any instance, with the possible exception of the Switzer's reagent. This agent, however, was abandoned because of difficulty in manipulation and lack of uniform results.

However, the Bureau is not at all discouraged over the proposition and believes further investigation might develop a product which would be satisfactory for laminating purposes.

In July, 1917, the Bureau was formally requested to produce 1000 square yards of rope paper to be forwarded to the Dayton-Wright Airplane Co. This paper was prepared on exigency order and forwarded at the earliest possible moment to its proper destination.

Paper Filters for Gas Masks

In February, 1918, there was started an investigation to develop a paper suitable for filtering "sneeze gas," to be used in connection with gas masks. This work was requested by the war gas-investigation division of the Bureau of Mines and was later continued with the cooperation of the Chemical Warfare Service of the Army.

The first problem which was assigned was to duplicate in this country a thin, crêped, tissue paper which was at that time being manufactured in England and used by the Allied armies. Development work was at once begun at a paper mill in Pennsylvania, and shortly thereafter a paper was successfully made which duplicated that being used abroad. Further work was done at this mill, and later development work was carried on at a mill in Wisconsin, producing a paper of very much the same kind. Both these attempts were highly successful, but in each case the plans of the Chemical Warfare Service were changed so that this paper was never produced in any great quantity for use by the American Expeditionary Forces. However, data were collected so that this material can be made at either of these mills on very short notice, and it is to be remarked that the organizations controlling these two mills practically permitted their equipment to be used as an experimental laboratory, although this necessarily interfered with routine work.

In order to meet certain changes in the shape of the canister desired by the Chemical Warfare Service, a paper which was very

satisfactory as a protection against "sneeze gas" was developed on the paper machine of this Bureau, and sufficient data were collected so that this paper can be developed here when needed. However, it would probably take some time to duplicate this paper on a commercial scale, although there is no doubt that it could be done in the course of a comparatively short time under the stress of war requirements.

In order to assist in the efficiency of this investigation, apparatus was set up at the Bureau with the help of the Chemical Warfare Service by means of which the paper developed was constantly tested so as to incorporate in its production any improvements which appeared desirable.

In this connection a gas house was built for the purpose ot conducting actual service tests of gas-filter paper as well as for determining the concentration of the gas by means of the nucleation apparatus.

While this work was in progress a large number of commercial papers were studied to determine whether any grades of paper were being manufactured which would be suitable for the purpose. It was felt, however, that a very special paper was necessary and that there was no paper on the market sufficiently porous to permit a man to breathe through it, and at the same time sufficiently compact to retain the small particles of "sneeze gas" which were injurious to the lungs.

As a result of these investigation it would appear that two distinct types of paper can be made in the United States on a commercial scale, both of which would be satisfactory as a protection against "sneeze gas" in the gas-mask canister. One is a very thin crêped tissue, about 70 thicknesses of which are used, while the other is a relatively thin porous paper, about 10 thicknesses being needed. In both cases the chief obstacle in the use of paper is the mechanical difficulty of attaching it to the gas-mask canister.

Paper Containers for Axle Grease and Saddle Soap

In the interest of the conservation of tin the paper section of the Bureau was requested to investigate the suitability of paper containers for materials such as axle grease and saddle soap.

With the aid of the war-service committee of the paper industry a line of samples representative of all the cartons now on the market and at all suitable for this purpose was secured. These ranged in size from a small box capable of holding about 4 ounces to a barrel of 30 gallons' capacity.

In general, the packages submitted could be divided into seven different classes: (1) ordinary cardboard boxes with slip-on covers; (2) cardboard boxes made from a heavily sized stock; (3) boxes lined with paraffin or oiled papers; (4) boxes lined with parchment papers; (5) boxes impregnated with paraffin; (6) boxes carefully treated with a suitable grade of varnish; and (7) boxes composed of three-ply board, the middle one being an asphalt-impreganted ply.

Classes 2, 4, 6, and 7 were found to be the most suitable for the axle grease. Any box seems to be possible for saddle soap, but the paraffin-impregnated boxes were less desirable because in some cases the heat caused by pouring in the melted soap was enough to cause the paraffin to run. Where a plain unsized or slack-sized cardboard box was used, the soap stuck to the fiber of the box, and thus there was some waste in removing the soap. The very liquid nature of the soap tended to soak off any parchment lining on the boxes, so that a box of this kind does not have the advantage for saddle soap that it has for axle grease.

Asphalt as a coating material was found to be distinctly unsatisfactory, both because it had little effect in lessening the moisture resistance and because it had a decided tendency to peel off and contaminate the contents of the box. An asphalt-impregnated paper used as a middle ply was reasonably satisfactory, and was free from the disadvantages mentioned above.

The varnished box (No. 6) was decidedly the preferred type. The varnish coating used was of such a type as to be very flexible. Some boxes coated with sodium silicate were received, but these were too brittle.

The tests were made on the assumption that the boxes of grease would be carried in a warm place, as, for example, under the hood of an automobile truck, or exposed to storage conditions in warm places, as in a steamer's hold. The boxes for soap were tested on the assumption that they would be filled by pouring in the soap in the melted form and allowing it to harden.

It is thought that class No. 2 boxes made from heavily sized stock would be sufficiently good for both purposes except under extreme conditions, and they are considerably cheaper than some of the more elaborate forms.

Round containers with slip-on covers are considered most suitable except where economy of shipping space is required. The covers should be of such a nature as to slip on and off very easily

and without injury to themselves or the box. This fact renders the complicated folding and locking covers open to criticism.

A very interesting field has been opened by the paper barrels which were received in this connection. In general, these were of two types: One is a barrel intended for the shipment of pitch or asphalt and as such has a comparatively low strength when empty. It is made entirely of pulp and is in one piece. The other is made of paper wound upon a mandrel under tension and is designed to cover a wide range of use. Paper-board heads are put in after the sides are completed. This barrel has considerable strength and will bear the weight of a man standing upon its side, even when empty.

PHOTOGRAPHY

General Photography

It is well known that the ordinary photographic plate when exposed in a camera does not reproduce exactly what the eye sees. This is because the ordinary plate is affected by only blue and violet light, for which the eye is relatively insensitive, and is scarcely at all affected by the green and yellow, for which the eye has its maximum sensitivity. These ordinary photographic plates are practically insensitive to red light, and are, therefore handled with safety in light from a ruby lamp. It has long been known, however, that photographic plates may be made sensitive to green, yellow, and red light by the admixture of suitable dyes to the emulsions coated on the plates, but the incorporation of such dyes in the emulsion generally reduces the sensitivity of the plate to blue and violet light, so that until very recently the commercial orthochromatic and panchromatic plates have been slower than the ordinary plates. Their use was, therefore, limited by the relatively long exposure required, until recent developments along the general lines to be described in the following paragraphs resulted in remarkable increases in the sensitiveness to yellow and red light.

A plate sensitive to these longer waves possesses some marked advantages over the blue and violet sensitive plate. A panchromatic plate reproduces more faithfully what the eye sees, and when exposed behind a ray filter or color screen it portrays objects which, on account of haze, smoke, etc., would be hidden from an ordinary plate, and also gives different contrasts depending on the nature of the light transmitted to the plate through the filter. The phenomenon of haze penetration by the longer waves is known to most outdoor photographers. Not only haze due to water vapor, but smoke haze, which looks bluish to the eye, is

largely eliminated by using light of longer wave length than that which is most effective in case an ordinary unscreened plate is used. Objects completely obscured by haze or smoke on an ordinary unscreened plate may be shown in good detail by using a panchromatic plate and a red filter. Such red sensitive plates, of course, can not be handled in the presence of the well-known dark-room ruby lamp, but must be developed in complete darkness or in a very week green light. To obtain the long-wave advantages of haze penetration and contrast mentioned above, the photographic plates must have the greatest possible sensitiveness to yellow, orange, and red light if the exposure times are necessarily short on account of rapidly moving objects or if the camera itself is in rapid motion, as is the case in aerial photography. When corrected camera lenses giving very bright images are not to be had, there is another argument for using photographic plates of the highest possible sensitiveness.

Photography as Applied to Spectroscopy

It is common knowledge that white light consists of a mixture of colors of different wave lengths of light, and most colors in nature are also compounds of several colors. These facts are observed when such sources of light are dispersed or spread out into spectra by suitable apparatus such as prisms or defraction gratings, and the analysis of such composite light is the domain of spectroscopy. The regular observations in spectroscopy in all spectral colors are now nearly always made by the use of photography; hence every modern spectroscopist is a photographer, and to photograph the entire range of spectral colors from the shortest ultra-violet to the long-wave infra-red requires a much broader knowledge of the numerous complex underlying elements of photography than that possessed by the average professional photographer. The names of Huggins, Draper, Vogel, Eder, Abney, and Schuman call to mind some remarkable applications of photography which were inspired by spectrocsopic researches.

Photographic Spectroscopy at the Bureau of Standards

The spectroscopy section of the Bureau of Standards began in 1914 an extensive program of measuring standard wave lengths throughout the entire range of the spectrum which can be observed photographically, and some of this work was published in the following scientific papers of the Bureau:

S 251. Interference measurements of wave lengths in the iron spectrum (2851A–3701A) with notes on comparisons of lengths of light waves by interference methods, and some wave lengths in the spectrum of neon gas.

S 274. Interference measurements of wave lengths in the iron spectrum (3233A-6750A).

S 302. Wave lengths of stronger lines in helium spectrum.

S 329. Measurements of wave lengths in the spectrum of neon.

Then it was observed that although observations of spectra were extensive in the so-called chemical regions—that is, in the short-wave lengths from ultra-violet to blue—and were fairly numerous in the green and yellow, there existed a great scarcity of data for the red and infra-red, these latter being the regions for which highly sensitive photographic plates could not be purchased. Accordingly, the Bureau of Standards decided to pay special attention to spectroscopic observations in the neglected regions of long waves. This involved the preparation and use of photographic plates specially treated to make them sensitive to red and infra-red light. Such sensitized plates have been successfully used at the Bureau since 1914 in a systematic study of the spectra of about 50 of the chemical elements. Some of the results of these studies have appeared as scientific papers, among which may be mentioned No. 312, "Wave-Length Measurements in Spectra from 5600A to 9600A;" No. 324, "Wave-Length Measurements in the Red and Infra-Red Spectra of Iron, Cobalt, and Nickel Arcs;" and No. 345 "Measurements of Wave-Lengths in the Spectra of Krypton and Xenon." Applications of such sensitized photographic plates were also made in connection with other scientific problems, as, for example, Scientific Paper No. 327, "Measurements on the Index of Refraction of Air from 2218A to 9000A," and especially to astrophysical problems. These later include Scientific Paper No. 318, "Application of Dicyanin to the Photography of Stellar Spectra," and "Photography of the Solar Spectrum from 6800A to 9600A," Astrophysical Journal (47, p. 1, 1918); "Solar and Terrestrial Absorption in the Sun's Spectrum from 6500A to 9000A," publications of the Allegheny Observatory, and an attempt at Baker City, Oreg. to photograph the red and infra-red flash spectrum of the sun at the time of its total eclipse on June 8, 1918.

Military Problems in Photography

During the war aerial observation early came to play a prominent part, and it became a matter of great importance to have a suitable panchromatic plate for aerial photography. Laboratories and research organizations in the allied countries were busily engaged in trying to produce plates of extreme sensitiveness or speed. The best commercial orthochromatic (sensitive

to blue, green, and yellow) and panchromatic (sensitive to all colors) plates were too slow for most purposes. For many years, however, physicists had used yellow and red-sensitive plates which greatly exceed in speed any of the commercial plates. These plates are prepared by bathing an ordinary photographic plate (sensitive to violet and blue) in certain solutions of aniline dyes, and at the expense of keeping qualities such plates may be made much more sensitive to red light than any plate known to commerce. After several years of experience with such plates in spectroscopic investigations by the Bureau, it seemed worth while to make an application of them to landscape photography when the United States declared war upon Germany. Accordingly, experiments were made in 1917 to determine the practicability of using the bathed plates for landscape photography with the hope that either this method might be a useful addition to the photographic methods of our military forces or that the experiments would lead to improved commercial plates which would incorporate sensitizing dyes in the photographic emulsions.

With apparatus that was inadequate to test the real merit of the bathed plate, a number of photographs of various objects were made which were encouraging enough to warrant a continuation of the investigation, using better apparatus (more suitable cameras and ray filters) and applying to the staining bath new dyes of British manufacture.

The attention of the science and research division of the Signal Corps was directed to these early results, and the Bureau was given the opportunity of comparing the stained plates with various plates used by the military forces. Among these were several types of British-made panchromatic plates which were then in use on the western front for aerial photography. A series of experiments soon showed that pinacyanol stained plates were at least four times as fast as the best commercial panchromatic plates then in use. In particular, plates stained with some new dyes of British manufacture were found to be much superior to any commercial panchromatic plates, not only in speed but also in the range of color sensitiveness.

These encouraging results led to the offer of the Bureau to supplement the photographic work of our military Air Service by adding to it a new method which would probably be of great military importance in special photographic work, such as the penetration of haze and smoke, detection of camouflage, etc., where the ordinary commercial plates could not be satisfactorily

used. The Bureau received the assurance of cooperation from the War Department and was invited by the Signal Corps to tes the bathed plates in aerial photography as soon as facilities per mitted. Extensive experiments were made at Langley Fiel during the spring and summer of 1918 under the generous auspice of the science and research division of the Signal Corps, and afte the armistice was signed the flying facilities of Bolling Field wer used to a limited extent to complete the experiments.

Early in 1918 a representative of the spectroscopic section o the Bureau, who was in France, was requested by the Frencl military authorities to assist the French photographic section in making fast color-sensitive plates. A temporary laboratory wa installed similar to the ones at the Bureau of Standards with th exception that the plate-drying cabinet was arranged so as t use air heated by a gasoline stove. This was necessary on account of the low temperature and high humidity prevailing in northern France in winter. The following experiments with bathed plate were conducted by this laboratory. Ordinary fast plates wer stained with pinaverdol and pinacyanol with ammonia, ortho chromatic plates were bathed in pinacyanol with ammonia, pan chromatic plates were bathed in ammonia. Each type of plat was used in three ways: Unscreened, with a deep yellow screen and with a red screen. The bathed plates were found to b somewhat faster unscreened than any plate actually used by th French. Using screens, the bathed plates were shown to be much faster, particularly for red photography. This matter was als considered of very great importance by the American Aviation Section, and Col. Dunwoody requested that one of the Bureau's physicists cooperate with them on experiments of this kind. Thi cooperation was offered, but was not strongly supported by th military authorities in America, largely on account of the fixed idea that bathed plates had only reached the experimental stage Considering the special equipment and technique required by such plates, their use at the battle front was held in abeyance with the hope that commercial panchromatic plates of sufficient speed would be forthcoming.

The success with which dye-sensitized photographic plates had been used in the Bureau's laboratories, however, convinced those engaged in this work that such plates had possibilities of extreme importance in special military applications and impelled th Bureau to demonstrate their value by careful measurements in the laboratory and tests in the field. In addition to the problems

of ordinary photography, the use of bathed plates with light filters involved (1) a study of photosensitizing dyes and of the spectral sensitivity which they imparted to ordinary photographic plates, (2) experiments to increase still further the speed of color-sensitive plates, (3) investigations of the spectral distribution of energy reflected from landscape, etc., (4) design and construction of new photographic lenses for use with red light, and other similar problems. These problems have been investigated by the Bureau with such success that the importance of dye-sensitized plates in military photography is now admitted by all, and the practicability of their use has been thoroughly demonstrated. The great advantage of these special plates in the taking of photographs from an airplane under adverse conditions is illustrated by Fig. 22.

Photographic Method of Detecting Camouflage

The Bureau, in cooperation with the United States Signal Corps and the United States Air Service, utilized a photographic method of detecting camouflage. The method consists of making two photographic negatives of the group of objects, one before the change and the other afterwards. A positive is made from one of the negatives, and this is superposed upon the other negative. If no change had occurred between exposures, the combination would form a field of practically uniform photographic density; but changes are plainly indicated by discontinuities of density. It is believed that the method has considerable commercial value for engineering and detective work, etc.

Protection of Moving-Picture Film from Heat of Lamp

A short description of the work done by the Bureau on this problem will be found in the article on "Radiometry."

Metallic Mirrors for Cameras

This subject is likewise treated in the article on "Radiometry."

Automatic Regulation of Diaphragm by Intensity of Light

A paragraph dealing with some work done by the Bureau on the practicability of a device for this purpose is described in the article on "Radiometry."

Production of Dense Barium Crown Glass for Lenses

The experiments which have been conducted in the Bureau's glass-making plant on the production of glass for photographic lenses will be found in the article on "Optical Glass and Optical Instruments."

Tests of Photographic Lenses and Camera Shutters

The experimental work performed in connection with the testing of photographic lenses and shutters is treated in the article on "Optical Glass."

PROTECTIVE COATINGS

Electroplating Investigations

Even before this country entered the war, numerous inquiries for information upon plating of military supplies were received by the Bureau, and a few preliminary investigations were made upon special applications of plating; for example, the production of copper propeller tips by electroplating. Soon after the beginning of the war it became evident that electroplating was being extensively required upon military supplies of most varied description, and that there were almost no specifications or methods of inspection relating to such work. Owing to the fact that in almost every case the plating was considered as an incidental and minor part of the manufacturing process, very little consideration was given to this subject by military officials in the early part of the war. In consequence, confusion and misunderstanding often arose in connection with the plating operations. There was held at the Bureau of Standards on March 27, 1918, a conference of military officials and manufacturers interested in electroplating. After a detailed discussion of the methods and requirements of the plating operations certain definite recommendations were made which were incorporated in a report of the conference, copies of which have been widely distributed. Among the recommendations of this conference was that one or more experienced platers should be engaged as plating advisors on military supplies. In accordance with this suggestion two experienced electroplaters were engaged by the Bureau and devoted most of their time to visiting various plants engaged in the manufacture of supplies to assist them in producing satisfactory plating.

To a great extent the function of plating upon military supplies was to protect metals, especially steel, from corrosion. Therefore it was necessary to devise and adopt methods of testing by which the relative value of plating as compared with other protective coatings could be determined. This section therefore cooperated actively with other sections of the Bureau in the preparation of specimens to be used in comparative corrosion tests. The principal test used for this purpose was the salt-spray test, by means of which it was readily shown that zinc coating

FIG. 22.—*Views from an airplane taken with an ordinary photographic plate, and one specially prepared at the Bureau's laboratory*

The penetration of haze by these special plates is clearly illustrated in the two pictures, taken at the same time of the same objects. Such plates were originally developed for use in spectroscopic work, thus illustrating the practical application of a scientific achievement

FIG. 23.—*Radio direction finder or coil aerial used in measuring the distortion of radio waves in the vicinity of trees, towers, wires, buildings, etc.*

FIG. 24.—*Model set-up in the radio laboratory to illustrate the use of the radio direction finder*

Radio signals are sent out from the two lighthouses and the direction from which they come is determined by the apparatus on the ship. The latter can therefore determine its position even in fog and under other conditions which render the lighthouse lamp invisible

exert the best protection against corrosion of steel, and that satisfactory zinc coatings may be produced by either hot dipping, sherardizing, or zinc plating (so-called electro galvanizing). Accordingly, in various specifications the Bureau urged the use of zinc coatings, not specifying the method of producing these coatings, but requiring a certain resistance in the salt-spray test.

In connection with the cooperative work with the Ordnance Department of the Army and with the committees on standardization of supplies for the War Department, it became evident that there was a lack of coordination between the various protective coatings required for different articles and for different kinds of service. A suggested classification of finish for metal parts was therefore proposed for use by the Ordnance Department and other branches of the War Department. The basis of this classification was the use or degree of exposure to which the articles would subsequently be subjected. While the proposed plan was never formally adopted by the military officials, it served in numerous cases as a guide in the specification of metal finish. This classification, together with a review of military applications of electroplating, was presented at a meeting of the Electro-Chemical Society and was also published in Metal Industry for November, 1918.

The three kinds of plating which were of most importance from the military standpoint were zinc, lead, and black nickel, upon all of which investigations were conducted at the Bureau, and information was furnished to manufacturers and to military officials.

When the value of zinc coatings for protection of steel against corrosion was fully realized, its use was extended to a wide variety of articles. For example, naval airplane parts, material used in shipbuilding, hardware for ammunition boxes, and parts of the fuze mechanism for high-explosive shells. It was found that satisfactory deposits could be produced from both cyanide and sulphate solutions, but that the cyanide solutions were usually more satisfactory for irregular shapes or parts with deep recesses.

Except for a few plants engaged in the manufacture of storage-battery fittings, lead plating was until recently almost a scientific curiosity. It was used very satisfactorily, however, on an extensive scale for plating boosters and adapters for gas shells and for lining certain of these shells. Another important application of lead plating was on the inside of underweight shells, whereby thousands of otherwise rejected shells were salvaged. A pre-

liminary circular giving detailed information upon the applications of lead plating was prepared by the Bureau and extensively circulated. In connection with this work the application of lead plating for lining chemical apparatus was investigated, and in cooperation with the officials of the Edgewood Arsenal a large tank was plated with lead to a thickness of 0.07 inch. Unfortunately, this experiment was finished too late to permit the general application of the process on the equipment at Edgewood before the signing of the armistice.

A large amount of hardware and equipment used by the Government is required to have a black or gray-black finish, the so-called "Government bronze." This is usually produced by the process known as black nickel plating. It may be applied to brass directly or after copper plating and to steel which has been previously plated with copper or with zinc. Great difficulty was experienced by the manufacturers in furnishing a satisfactory finish, but after a great deal of work the Bureau was able to throw considerable light upon the behavior of such solutions and to devise simple methods of operation and testing.

There were many demands for information on copper, nickel, and tin plating which frequently required visits to the plants in order to determine and remove the cause of the difficulties experienced.

In addition to the normal applications of plating many unusual problems arose in connection with which the Bureau was able to furnish some assistance. Among such problems may be mentioned the following:

In cooperation with the Bureau of Mines the Bureau assisted in the development of a process by which it was found possible to produce heavy nickel articles, such as seamless tubes, etc., for which there was a considerable demand in the nitrate manufacture and the separation of helium. It was arranged that the Government was to have the use of this process during the war and for six months thereafter. So far as is known this method has never been operated upon a manufacturing scale.

It was found that by a simple electrotyping process it was possible to reproduce at a very slight cost the master range finder scales used for producing the lines upon range finders.

The Bureau cooperated with the New York Navy Yard and assisted them in securing the equipment and personnel for producing various plates by electrodeposition.

The Bureau was requested to investigate the possibility of relining worn-out guns with a sufficiently heavy coating of nickel, iron, or cobalt to permit the rerifling of the guns. The limited force available prevented any exhaustive research upon this problem, the solution of which on a large scale does not seem to be very promising. More recently a similar problem has been submitted, namely, of relining defective recuperator cylinders used on 75-mm. or larger guns. In the preparation of these cylinders it is necessary to have an absolutely smooth surface, which is obtained by "lapping." In the process of manufacture many defective cylinders have been rejected, and it is desired, if possible, to salvage these cylinders by plating a sufficient coating of nickel or copper to permit relapping to a true surface. The possibilities of this process are now being investigated.

The Bureau was called upon on numerous occasions to assist in the design of plating equipment to be used for military supplies both in privately owned and Government plants. Among the latter may be mentioned the New York Navy Yard, Marine Depot in Philadelphia, and the Naval Aircraft instruction schools. In addition visits were made to the principal arsenals and navy yards and recommendations were made regarding the equipment and processes for such work.

Bituminous Materials

The bituminous products are remarkably resistant to acid and alkaline attack, their physical properties vary from liquid asphaltic oils and tars to hard and brittle asphalts and pitches, and they are susceptible to modification through this range by blending and fluxing.

These physical characteristics have given them a wide and general application in building construction, and they were called into important uses by the military authorities not only for such recognized purposes as prepared and built-up roofing, preservation of timber and waterproofing, but specifically as a coating for steel and concrete ships, a coating for hand and rifle grenades, for marine glues used in the construction of pontoons for naval aircraft, etc.

In the preparation of specifications for prepared roofing it was realized that war conditions had seriously interfered with the normal production and quality of the raw material used in its manufacture, and it was necessary therefore to make the specification less exacting than usual so as to obtain the essential produc-

tion. The present specification was developed in cooperation wit the War Industries Board and manufacturers producing prepare roofing and includes instructions to inspectors as well as method of inspection and test. Large quantities of material were ob tained under this specification which were used on cantonment hospitals, and warehouses built in various sections of the countr

The inspection and testing of this material required a grea deal of laboratory work, some thousand samples having bee examined, representing a million squares of roofing. As migh be expected many leaks developed in these roofs, but from suc information as could be obtained they appeared to be due t faults or carelessness in laying rather than defective materia Several cases were investigated by members of the Bureau i cooperation with officers of the construction division of the Arm and recommendations for repairs were made which did no necessitate relaying. The recommended method of repairs in cludes a specification for a roofing cement to patch holes o larger areas in which the exact position of the leak can not b located. This practice is now being followed and results i satisfactory repairs at minimum expenditure of time and mone and with maximum convenience.

A specification for built-up roofing is still in process of develop ment. This type was not so urgenty required during the wa and with the signing of the armistice the immediate need passe There is a normal demand for a specification for this type o roofing by the Government, and it is expected that those inte ested in the subject will be called together to consider the develop ment of a uniform specification as soon as other more urgen demands permit.

For covering the interior of steel ships, including the co bunkers, it was necessary to produce a coating which woul protect the metal effectually against corrosion in places whic were not readily accessible for inspection and which were alway wet with salt or bilge water. Likewise the coating must adhe without cracking or flowing when the vessel is laid up during co winter months and must not be injured by the severe conditio encountered in the engine and boiler rooms. Such investigatio required a study of the service conditions, the development o tests which would duplicate these conditions, the production o material in the laboratory to meet these tests, and finally th preparation of specifications to insure the quality of the materia accepted.

Considerable work has also been done in connection with concrete ships. Such vessels had never before been used to any extent, and required special treatment. A ship is subjected to great and various strains and can not be made perfectly rigid, so that, although concrete is usually considered a rigid material, it was called upon in this case to act as an elastic substance, and with proper reinforcement was found to stand much distortion without failure.

Small hair cracks may develop in the concrete, and one of the problems presented was to cover the outside of the structure with an elastic waterproof membrane which would bridge such small cracks. The coating must not be affected by water, must not flow when subjected to the pressure of the water when the vessel runs at maximum speed, and must present a suitable surface for the application of antifouling, boot-topping, and camouflage paints over it. All of these conditions were considered and a number of products tested in an effort to obtain one which seemed to meet conditions of service best.

Another problem in connection with concrete ships was the production of a satisfactory inside coating for oil tanks. Many of these ships were to be used as tankers for the transportation of a variety of crude and refined oils. The problem was complicated by the presence of water in the oil and also by the fact that these tanks might frequently be filled with water as ballast on return trips. This, of course, made necessary a coating resistant to both water and oil.

After an extended investigation it was recommended that a long oil varnish, commonly called spar varnish, be adopted for the inside coating, and a bituminous coating for the outside. It was also found that treating the concrete surface with a solution of magnesium fluosilicate was an advantage, as it had a hardening effect and gave a better bond.

A satisfactory marine glue was required both by the Army and Navy to cement canvas to light pontoon construction, as the foreign product was no longer available. The material must be adherent and elastic after frequent wetting and drying, must remain tacky and pliable and be waterproof and durable. Many commercial products were tested and analyzed so as to know what materials could be used in producing a satisfactory product. As a result, a specification was developed in which the requirements were based on performance so as to insure a satisfactory material with the minimum restriction on composition.

Hand and rifle grenades required a coating which would dry hard on a greasy surface, as it was not practicable to clean them after machining. A hot coal-tar pitch of relatively low penetration and high melting point was applied to both the inside and outside of the grenades and excess drained off.

The coating for the inside of high-explosive shells required different characteristics. It had to be free from any lead or manganese compounds, should not dry hard, but remain tacky so as to bond with the molten T.N.T. with which the shells were charged, and should not have any effect on the efficiency of the explosive. A Gilsonite fluxed with a soft Bermudez asphalt and thinned with a slight volatile petroleum product appeared to give a satisfactory coating.

A war-time specification was also prepared for the construction division of the Army for creosote oil for wood preservation. This specification was not put in general use, as contracts had been placed prior to issuing of the specification, and much inferior material has been used on that account.

Varnishes

Early in 1917 the Bureau rendered a report to the Aviation Section of the Signal Corps showing the relative waterproofing qualities of different treatments on wood. This information, which was requested by the chief signal officer, showed that a high grade of spar varnish was the most satisfactory transparent coating for waterproofing the wooden parts of airplanes and for protecting the doped fabric of the wings. The varnish which seemed to answer the requirements most satisfactorily consisted of a china-wood, oil-resin varnish, and at this officer's request a specification, based entirely on physical requirements of the film, was drawn up, which appears to have been the first specification for spar varnish the basis for which was performance rather than composition. In October, 1917, there was a meeting at the Bureau of representatives of the various varnish companies and of the Bureau of Standards. This committee constituted the varnish subcommittee of the standards committee of the Society of Automotive Engineers, and the committee adopted a specification very similar to the one furnished by the Bureau's laboratory to the Signal Corps.

About this time the various branches of the Aviation Section began calling for lists of varnishes that had been approved under this specification. The Bureau had made examinations of many samples of varnish under this specification and had complete

data on exposure tests, so that a small list of approved varnishes was immediately available. A very large number of samples to be examined continued to be submitted, and after exposure tests were completed, those which proved satisfactory were added to the approved list. As a result there was always available for the chief signal officer a continually growing list of approved varnishes that could be ordered by any of the airplane manufacturers on brand.

In December, 1917, a chemist from the Signal Corps laboratory, part of which was then located at the Bureau, was detailed to help in carrying out the very great amount of experimental work and testing which was required by the more than 200 samples of varnish which were submitted for test. In May, 1918, when the Signal Corps laboratory was moved to Pittsburgh, all the work which had been carried on at the Bureau was transferred to the new laboratory.

At a conference with representatives of the allied nations, the specification for spar varnish for airplanes, with practically no changes from that originally prepared, was approved and adopted by the International Aircraft Board. The same specification has since then been adopted by practically all branches of the Government, including the Bureau of Construction and Repair, Navy Department; the United States Shipping Board; the United States Railroad Administration; the General Supply Committee; and the War Department. This specification has proved to be one of the most generally applicable to all classes of high-grade varnish for all purposes, although the specification finally adopted by the Signal Corps of the Army contained several slight modifications, which were made after the removal of its laboratory to Pittsburgh.

In order to prevent the explosive charge in high-explosive shells from acting on the metal and to prevent rotation of the charge independently of the shell, it is necessary that the interior cavity of the shell be coated with a varnish. Such a varnish should be free from lead and other heavy metals, so that no reaction will set in between the explosive charge and the coating. The specification to cover a satisfactory varnish of this type was furnished in April, 1918, to the explosives section, Engineering Division, Ordnance Department of the Army, for a shellac-resin mixture cut in denatured alcohol. Such a varnish had previously proved satisfactory. Another specification covering material for this purpose, but which did not limit the manufacturer to any specific

composition and which would have the proper softening point to form a good bond between the shell and the explosive in hot loading, was also furnished to the Ordnance Department.

For coating the metal ends of powder containers the Ordnance Department had specified an acid-proof lacquer. This caused considerable confusion, since all oily resinous materials contain a certain amount of organic acidity, and the Bureau was called upon to settle this question of dispute between the manufacturers furnishing the lacquer and the War Department inspectors, who were guided by the existing specification. As a result the Bureau recommended spar varnish conforming to the airplane spar varnish specifications as the most suitable coating for the metal ends as well as for the fiber container where it is crimped into the ends.

The coating of the interior of rifle and hand grenades presented a somewhat different problem from the coating of the high-explosive shells. In the process of manufacture the grenades are sent to the loading plant in a very greasy, dirty condition. In order to expedite production it was not feasible to clean the grenades, and a coating material was therefore desired that would adhere to the greasy interior surface. For this purpose certain loading stations had been using a varnish which consisted of a solution of resin in a certain type of gasoline which resulted as a by-product in a manufacturing process. This gasoline was available only in limited quantities, and in order to overcome this difficulty samples of the gasoline were submitted to the Bureau. It was found that it was nothing but ordinary automobile gasoline containing a considerable quantity of sulphur, free and in solution. In experiments with the varnish made from this gasoline and resin it was found that the varnish had no particular virtues in adhering to greasy surfaces and that good continuous films on the interior of grenades were not always obtained. However, when a solution of resin in solvent naphtha was used, a much better film was obtained. A recommendation to this effect was made to the trench-warfare section of the Ordnance Department. It later developed that the manufacturing process allowed heating of the grenades, and this enabled them to use a bituminous varnish which appeared to be more durable.

Enamels

Soon after extensive varnish testing was under way, it was realized that the use of an enamel would much better protect the doped fabric of airplane wings, and such an enamel should be

light in weight, opaque, and very durable; so experiments on various types of enamels were begun. As a result of the preliminary information obtained the Bureau of Construction and Repair, Navy Department, drew up a specification for airplane-wing enamel which required the necessary physical qualifications of a satisfactory enamel and limited the manufacturer to a specific composition of pigment. It developed that it was impossible to use certain types of pigments with airplane spar varnish, which had been proved to be the most satisfactory vehicle. Further experiments were made to determine which pigments worked most satisfactorily in a vehicle of spar varnish, and in cooperation with the Bureau of Construction and Repair, which made similar experiments, the airplane-wing enamel specification was finally changed so as to retain the physical requirements of the original specification, but eliminated the composition requirements of the pigment.

Specifications for high-grade air-drying and baking enamels were also drawn up for various branches of the War Department. These had for their basis the spar-varnish specification and in general called for suitable pigments in a vehicle for spar varnish conforming to the airplane spar-varnish specification. The air-drying enamels, especially the low visibility gray, were used exclusively on the hydroplanes manufactured by the Navy Department, and black enamels, both air-drying and baking, were used for finishing the metal fittings on hydroplanes as well as for giving a black finish on military hardware parts. A blue air-drying enamel consisting of a pigment in airplane spar varnish is used for coating the wires and cables of airplanes.

Several samples of baking Japan that were to be used for coating the cases of submarine mines were examined for the Bureau of Ordnance of the Navy Department. These Japans were backed on at very high temperatures (between 250 and 300° C) and had to resist the severe action of being submerged in salt water.

Slushing Oils

Shortly after the armistice was signed, the Bureau received many requests on rustproofing compounds which could be used in storing large quantities of equipment of all types. Examination of some of the samples of rust preventives which had been submitted to the Bureau showed that they varied greatly in composition and in quality. After many practical tests specifications were drawn up to cover transparent slushing oils of brushing con-

sistency and dipping consistency, and opaque slushing oils c brushing consistency. These specifications did not limit manufac turers in any way as to the composition, but were based entirel on practical tests. A small mimeograph pamphlet on "Notes o the Protection of Metal in Storage" was prepared. This deal in a general way with the question and included the specification Technologic Paper No. 176 has been issued recently and deal more fully with slushing oils.

Fireproofing of Fiber Board

Some of the Army hospitals were constructed from a wate proofed wood-fiber board. This construction proved to be a ver great fire hazard and resulted in the complete destruction by fi of one or more of the hospitals. The problem of fireproofing th material was given to the Bureau, and experiments showed tha when treated with a solution of sodium silicate and water th combustibility was very much reduced. It was recommende that as far as possible the buildings constructed of this boar be discarded and further use of this building material be di continued, but that where the buildings could not be vacate all the interior walls be treated with a spray coat of a fireproo ing solution of water glass.

Fire-Retarding Paints

In the summer of 1917, at the request of the Bureau of Yar and Docks, Navy Department, work was commenced on a numb of samples recommended as fire-retarding paints. On Novemb 1, 1917, a report was made to the above Bureau, and since tha time a number of other fire-retarding paints have been tested f various branches of the War and Navy Departments. The sub sequent work has only tended to confirm the original conclusion which are as follows:

> Since this investigation was intended to give information regarding fire-retardi treatments for interior surfaces, the tests were not designed to give information as the durability of the coatings on exposure out of doors; but since any interior surfa may be subject to an occasional wetting, it is believed that the relative behavi before and after soaking in water is of importance. It should be noted that the p cents of efficiency in fire retarding, from the arbitrary methods necessary in maki the calculations, are relative only, those having the higher ratings showing the great resistance; but the difference between the best and the poorest is actually sma The value of any particular treatment can best be judged by reference to its relati to well-known common methods of coating wood. Thus, whitewash ranks amo the most resistant materials, indian red in linseed oil among the least resistant, a white lead and zinc oxide in linseed oil are intermediate.
>
> The general conclusions from this investigation are that while practically all pai coatings have some fire-retarding action, none of the materials examined afford ve great protection. All the samples tested were materially damaged by applicati

of the flame for a few seconds. It is noted that both sodium silicate and whitewash rank relatively high. Both of these have the advantage of cheapness, and there is no reason why both can not be used on the same surface. It is believed that for interior wood surfaces the application of sodium silicate solution followed by a coat of whitewash may be more efficient than either one used alone; but, as mentioned before, no treatment of wood after erection can be expected to act as an efficient fire preventive, and the use of such materials should not be taken as an excuse for omitting any precautions tending to prevent danger of fire starting or providing ample facilities for stopping any fire as soon as it starts.

It is believed that wood construction, no matter how the wood is treated either before or after erection, will involve serious fire risk, and whenever practicable noncombustible material such as metal, cement, etc., should be used.

We, therefore, now recommend that claims as to fire-retarding properties of paints be entirely disregarded, since practically all paints have some slight value in this respect, and the difference between the best and the poorest is practically negligible.

Paint Specifications

A very large amount of work was done in preparing specifications for paints for various purposes. For example, at the request of Emergency Fleet Corporation, specifications were prepared for white paint, outside slate-color paint, boot-topping paint, and copper paint for use on wooden ships. These were sent with a letter to the United States Shipping Board, August 3, 1917.

The Bureau cooperated with the Paint Manufacturers' Association in examining numerous specifications for paint for steel ships recommended to the Shipping Board. Specifications for a paint for steel helmets were prepared for the Chief of Ordnance of the Army. After testing a number of samples of very rapid-drying paints for use on projectiles, a specification was prepared and sent with a letter to the Edgewood Arsenal at Baltimore. All projectile paints of which the Bureau has any knowledge that were used during the period of heavy production were of the type covered by the above-mentioned specification, but the Bureau has been unable to learn whether the proposed specification was ever issued. The War Department has, however, specifications for projectile paints of a different nature from the above, as they are much slower drying and it has not been learned whether projectile paints according to the issued specifications have been used or not.

Numerous paint specifications were prepared for the various branches of the War Department, the War Industries Board, etc.

Paint Testing

A very large number of samples of paint have been tested for the War and Navy Departments, and this work still continues.

The Railroad Administration specifications for all paint materials prescribe that methods of test approved by the Bureau shall prevail in all cases of dispute, and considerable work has been done in advising the railroad chemists regarding methods.

Since the signing of the armistice the Bureau has been called upon by the Ordnance Department of the Army for advice relative to the painting of guns, shells, and other equipment for storage. Experiments were carried out to determine the thickness of paint films on shells after brushing and spraying; it was found that three coats of a suitable paint could be applied to shells without increasing the diameter sufficiently to exceed the tolerance permitted, thereby obviating the necessity of cleaning the shells should their use be required.

PUBLICATIONS AND INFORMATION

New Scientific Publications

The Bureau of Standards prepared and published during the war many special reports, most of them confidential, on military technologic subjects. For example, a series of confidential reports on the strength and other properties of aluminum alloys; a series of special aeronautic instruments circulars, describing a wide variety of aeronautic instruments, their design, construction, and methods of test and calibration; and a series of power-plant reports, relating to the design and test of aeronautic engines and auxiliaries, such as radiators, carburetors, etc., and the relative merits of various types of airplane fuels. A series of confidential news bulletins recounting recent developments in the Bureau's military work, besides many thousands of scientific and technologic papers and circulars were distributed regularly to technical officers and employees throughout the military services.

Metric Literature

General Order of the United States Army, dated January 2, 1918, reported that the General Staff of the American Expeditionary Forces in France had adopted the metric system. The order read in part:

> The metric system has been adopted for use in France for all firing data for artillery and machine guns, in the preparation of operation orders, and in map construction. Artillery and machine-gun material intended for service abroad is being graduated accordingly. Instruction in the metric system will be given to all concerned.

The urgent demands for metric pamphlets, charts, paper comparison scales, and tables of equivalents began at once and kept up briskly throughout the war and, in fact, have not yet ceased.

The metric literature issued by the Bureau and thus distributed by the thousands of copies among the technical services of both the Army and Navy in France and America included:

1. A graphic wall chart of the international metric system (44¼ inches by 28¼ inches); giving tinted graphic and numerical comparisons of customary and metric measures, and metric tables.

2. A descriptive pamphlet of the international metric system showing the uses of the various units, giving a brief summary, the important equivalents, and a statement of the legal status of the metric system.

3. A 30-cm (12-inch) comparison scale printed on paper, permitting direct visual translation from centimeters or millimeters to inches or binary fractions of the inch.

4. A document entitled "Units of Weight and Measure—Definitions and Tables of Equivalents," a rather complete statement of tables of equivalents covering all the more commonly used units, together with official definitions and equivalents of basic units of length, area, capacity, and mass.

5. The Metric manual for soldiers, which is described in the next section.

Soldiers' Manual of the Metric System

When the General Staff of the American Expeditionary Forces adopted the metric system of weights and measures for use of our forces during the war, the Bureau, as mentioned above, had many demands for metric material for instruction work here and abroad. To meet this demand in a manner especially adapted for the use and information of the average soldier, the Bureau prepared a metric manual of 16 pages (10 by 15 cm). This was known as Miscellaneous Publication No. 21 of the Bureau of Standards, entitled "Metric Manual for Soldiers—The Soldier's Manual of the System—An International Decimal System of Weights and Measures, adopted as the legal standard by France and 33 other nations and in world-wide use." The aim was to give the American soldier a practical grasp of the system by graphic examples of the units, citing dimensions of objects familiar to the average soldier. The publication included a sketch of the origin of the metric system with brief tables of equivalents and a glossary. About 100,000 of these manuals were distributed, and the plates were made available to the bureaus of the Army or Navy desiring to use them for printing special editions. The Superintendent of Documents also placed the manual on sale. Abundant evidence has shown the usefulness of this little manual in teaching the metric system of weights and measures, which was used with such success by the allied forces in the war.

Technical Information Activities

On account of rapidly changing conditions during the war with its extensive use of all scientific and technologic resources, the methods of combat and communication were being constantly improved or replaced through the use of new inventions or as a

result of scientific discoveries. The rapid and continuous circu lation of accurate technical information to the workers in scientifi and technologic fields having military application therefore becam of paramount importance.

Pertinent technical information was available from authoritie and experts in all branches of physics, chemistry, and engineerin from the various offices of the War and Navy Departments an from research agencies of civilian character engaged on militar problems here and abroad, such as the National Research Counci National Advisory Committee for Aeronautics, etc.; as a mean for disseminating this material an "information section" wa inaugurated in the central office of the Bureau of Standards i which confidential information of the type just described was r ceived. All such information was carefully digested with referen to the needs and activities of every section of the Bureau, an notices of receipt and abstracts of such information were distribute promptly to the experts concerned with the particular subje of each document. In this way a means was provided by whic timely and effective contact could be accomplished among worke in related subjects of military research, and results were obtaine in the way of speeding up exigent work which otherwise woul have been quite impossible.

The information work was further extended by the publicatio at frequent intervals of a series of confidential bulletins givi timely news items regarding military work carried on at t Bureau of Standards. This series was made up of 26 number approximating 65 000 words. These were sent to a maili list comprising the principal technical officers and employees i the Army and Navy organizations in this country and in Franc These bulletins give short abstracts of the method of solution an often also a résumé of the results obtained on new researches an investigations, and so afforded a ready means of supplying tec nical experts throughout all services with up-to-date informatio regarding recent advances at the Bureau in their respecti specialties, aiding also to set up contacts by which experts in an field included might be enabled to obtain cooperation or assistanc

RADIO COMMUNICATION

Radio in Warfare

The use of electric waves for telegraphy without wires ha become recognized in 1917 as indispensable to warfare. It mad possible communication with remote places and rapidly movin

troops. The United States was far behind other countries in the application of radio communication to the above purposes, but its immediate importance was clear.

The absolute necessity of radio in modern warfare is apparent when one considers the tremendous complexity of the fighting methods. The firing of artillery no longer consists merely in the pulling of a trigger by a man who looks at his target; the use of heavy guns depends not only on the properties of explosives and the application of ballistics, but also on aviation, radio, meteorology, map making, and many other sciences and arts. The gunner does not see the object at which he is shooting nor does he even see the airplane which is watching the mark and telegraphing the results of his shots to him. All methods of conveying signals are used, from the most primitive to the most advanced, from a human courier to electric waves. Radio has been used not only to give orders, direct battle, and listen to the communications of the enemy, but also for very different purposes, such as the issuing of propaganda, the conduct of armistice negotiations, and the saving of ships at sea. In the several allied countries large laboratories were established for the investigation of radio waves and the development of apparatus which would utilize them in the most efficient manner. Existing scientific laboratories were utilized for research on the more fundamental principles and instruments, and the military services established special laboratories of their own to design the military equipment.

When this country entered the war, the Bureau of Stadnards was ready with methods, apparatus, and trained personnel for the solution of many of the fundamental problems which confronted military men. Among the problems which had to be solved, and solved quickly, were: (1) The establishment of high-power transoceanic radio systems for use in case all the cables should be cut; (2) the development of low-power radio equipments which should send out just enough but not too much power for communication in the congested area of any given sector at the front; (3) a means for the location of enemy radio stations and airplanes, submarines, and ships; (4) apparatus for communication with and from submarines, particularly when totally submerged; (5) simple and reliable apparatus for radio telephoning; (6) the production of radio apparatus which could be easily carried and yet comprise everything necessary to make the most effective use of radio waves; (7) the training of great numbers of men in a complex and rapidly changing subject.

Fortunately, certain radio devices existed which gave prom of solving a number of the more important problems. Am the most noteworthy of these devices are the electron tube the direction finder. Both were being developed at the Bur of Standards. The first of these, the electron tube, is a de which makes possible radio telephony. The direction finder simple apparatus, which not only receives the radio waves, which can also be turned in such a way as to determine the di tion from which the waves come. At the beginning of the although these devices were imperfect and their principles little understood, both scientists and military engineers saw them the promise of great utility and means for the solution problems which would give our Army great superiority over enemy. Much has been done in the application of the scientific knowledge to the development of these instruments.

Relation of Bureau of Standards Radio Laboratory to Milit Services

The Bureau of Standards has been a center for radio resea work. Besides its own radio laboratory, there were located the Bureau during the war the following Government establ ments: Naval radio research laboratory; naval aircraft ra experimental laboratory; research laboratory of Signal Co intelligence division of Army, radio laboratory. The Bur furnished laboratory facilities for these independent organizati and assisted by testing instruments, etc.

Accommodations were provided for this work in the electr building of the Bureau and in another building which was erec on the Bureau's grounds exclusively for radio work. Equipm was provided and research undertaken for the many lines specialized measurements which were required.

The presence of the Signal Corps and naval laboratories assis the Bureau in planning its own radio work along lines wh would assist the military services. Besides contributing dire to the military radio problems, much of the work on the Burea radio research program was necessarily of a fundamental nat on principles, measurements, and the efficiency of design apparatus. Without such work the Bureau would have b unable to advise upon many of the problems submitted to it to effectively carry out its other undertakings.

The Bureau was able to furnish information, advice, a assistance upon radio matters to the National Research Coun

as well as to the various branches of the Army and Navy Air Services. The most direct relations were maintained with the Signal Corps, a considerable part of the Bureau's work having been done specifically for this organization. This work was supported in part by funds transferred to the Bureau by that Corps. During the war period the staff of the Bureau's radio laboratory numbered about 40 men, and besides these, 5 men were detailed from the Signal Corps to assist in special investigations. Six additional persons were detailed for short periods by the Signal Corps and the Navy to receive instruction in laboratory work.

That the Bureau's cooperation was appreciated by the military services is indicated by the following statement contained in the report for 1919 of the Chief Signal Officer to the Secretary of War:

> The outcome of this research work has been of vital importance to the Signal Corps, and it is felt that every additional facility should be afforded to the Bureau of Standards so that it may continue to collaborate with the Signal Corps on these special problems.

Cooperative Activities

A notable event following America's entry into the war was the visit of the French Scientific Mission early in 1917. The Mission included Prof. Henri Abraham, of the University of Paris, who has been a leader in applying electrical science to radio apparatus for war purposes. The French mission brought a large quantity of scientific military apparatus and deposited it at the Bureau of Standards. This was demonstrated to Army and Navy officers and scientific men employed upon military problems.

In 1918 an interdepartmental radio conference was organized which held meetings every two weeks at the Bureau of Standards. This conference was composed of the technical radio men of the Navy, Signal Corps, and the Bureau of Standards, and at each meeting one of the important problems of radio was discussed. These meetings were very valuable, both for the interchange of information and because through this means the radio men of the Government were kept in touch with one another's work.

In a number of the problems upon which the several radio organizations were working along related lines, cooperation was furthered by informal conference. Many investigations were carried on directly for the military services by the Bureau, as detailed later in this report. Besides those mentioned, many

special researches were undertaken at the request of the Arm and Navy.

Information and Reports to the Army and Navy

A considerable part of the time of the radio laboratory wa devoted to furnishing information by letter and informal co sultation, and to aid in this work a systematic file of technic data on radio subjects was established. The subjects covered i this consultation work included principles of radio waves a apparatus, scientific and commercial data, radio organization instruction material, standard symbols and terminology, biblio raphies, applications of radio to various purposes, and the who range of technical subjects covered in the laboratory work. O a number of occasions demonstrations of radio apparatus a instruction in radio methods and measurements were given Signal Corps officers.

General reports on the Bureau's radio work for the Sign Corps were prepared and furnished to that organization under t dates of July 31, 1918; October 11, 1918; December 17, 1918; a July 30, 1919. A general report on the radio work for the Nav of December 20, 1918, was supplied to the Navy Departme Summaries of the radio work in progress, dated August 7 a November 6, 1918, were sent to the Signal Corps, the Navy Depar ment, Air Service, and to the other military organizations throu the National Research Council. Outlines of the radio work progress and planned were sent to the Signal Corps.

Numerous copies of about one hundred technical reports the various phases of the radio laboratory work were sent to t military services. These reports varied from brief descriptio of work done to extensive treatises on radio subjects.

Radio Instruction

Among the problems which the Signal Corps had to sol immediately upon entering the war was the training of gre numbers of men for technical service in the field. This was task of peculiar difficulty so far as radio is concerned, since it a complex and rapidly changing subject. The available literatu was not up to date, either for students or instructors. Instead the few scores of trained radio operators and a handful experienced radio engineers that were available before the wa there was need for thousands of men skilled in this subject.

Intensive training was carried on at the cantonments and colleges and schools designated by the War Department througho

the country. An acute need for suitable radio textbooks was felt by the men secured to act as instructors in these schools. The general plan of radio instruction was outlined by Signal Corps officers at a conference of college and university representatives, held at the Bureau of Standards on December 29, 1917, and, although the Signal Corps courses of radio instruction were decided upon at that time, but little instruction material was available.

From the above date the Bureau of Standards' radio staff assisted in the preparation of instruction material. This was accomplished by consulting the data compiled by the Signal Corps officers and by preparing original material. The principal contribution of the Bureau was the preparation of a radio reference book and a textbook for elementary training, both of which are described below.

A number of brief instruction pamphlets were prepared by the Bureau of Standards and submitted for use in connection with various parts of the Signal Corps course. In addition, pamphlets compiled by the Signal Corps were submitted to the Bureau for criticism and were revised to a greater or less extent by the Bureau's radio staff.

"Radio Instruments and Measurements"

At the December 29, 1917, conference, the Bureau of Standards presented the nearly completed manuscript of a treatise on radio principles, measurements, and theory. This was offered as a reference book which would be useful to the instructors in giving the radio courses and to students training for radio officers. The Signal Corps approved this manuscript and requested its speedy completion and publication. By concentrated effort the manuscript was completed and sent to the printing office in January. It was finally issued on March 23, 1918. The Signal Corps was supplied with 2000 copies.

This book, "Radio Instruments and Measurements," Circular No. 74 of the Bureau of Standards, covers the fundamental theory of radio and the more important instruments, measurements, and formulas actually used in this work, subjects not covered by any other publication. Thus there were made available unpublished results of radio work which had been carried out in the laboratories of the Bureau. One of the chief characteristics of the book is its treatment of the underlying principles of radio by the simplest methods of ordinary alternating-current theory. Previous books have presented radio as a complicated subject based upon abstruse

theories, thus making it mysterious and difficult to grasp. Th book, commonly referred to as "Circular 74," is a publication o 341 pages, with an index and 224 illustrations.

Thousands of copies of "Circular 74" were furnished to men i the universities, the Navy, and the Army, besides those furnishe to and through the Signal Corps. It has been used in the trainin of thousands of students. Many letters have been received b the Bureau from various sources, military, commercial, an academic, commending Circular 74, and stating that it has bee found very useful in many lines of work.

One criticism of Circular 74 was that it was issued in pap covers, uniform with all other Bureau of Standards publication The demand for a cloth-bound edition was recognized by a com mercial publishing company, the Wireless Press. This compan reprinted Circular 74 with a smaller page size and cloth covers an has sold a great many copies.

"The Principles Underlying Radio Communication"

Circular 74 having been found satisfactory as a radio referen book for the use of instructors and officers, the training sectio of the Signal Corps requested the Bureau of Standards in Apr 1918, to prepare an elementary textbook for general use by e listed men and others. It was desired that this book cover t fundamental principles of electricity and dynamo-electric m chinery, as well as radio circuits and apparatus. Such a boo was needed as the basis for various pamphlets to be issued Signal Corps radio apparatus. None of the previously availab books had been found satisfactory.

An understanding as to the outline of the book was reached wi the Signal Corps, and the active work of preparation was beg in June, 1918. The book was required within three months. was prepared by a syndicate scheme of authorship which w rather an innovation in the preparation of scientific textbook The regular radio staff was temporarily augmented by six membe of college faculties who were well equipped for this task. D to the haste necessary in preparation and because of the collabor tion of a number of writers, coordination of the material was pa ticularly difficult.

The work was completed and turned over to the Signal Cor in September. The Signal Corps was unable to proceed wit publication until December, and the book was finally issued i March, 1919. While the book was in preparation, a first editic

of 50 000 was contemplated. After the signing of the armistice this was reduced, and the first edition numbered 6000 copies.

The book is nonmathematical and profusely illustrated. It contains 356 pages, $4\frac{1}{2}$ by $7\frac{1}{2}$ inches, in a flexible binding. It is suitable for the instruction of men who have had the equivalent of high-school education. It has been adopted as a radio textbook in the Army and the Navy, a number of colleges, Y. M. C. A., and other schools. The Bureau of Standards has received many favorable comments on this book from schools, manufacturers, inventors, amateurs, and students.

Radio Direction Finder

A few turns of wire wound around a wooden frame arranged so that it can be rotated constitute an aerial which not only receives radio waves but also determines the direction from which they come. Detecting apparatus connected to this simple device receives the wave in much the same way as the more familiar antenna which is seen in connection with most radio stations. The current circulates around the coil instead of oscillating up and down as in an antenna. This direction finder is a much smaller structure than an antenna, being, in fact, usually only about 4 feet by 4 feet in size. It is not as powerful a receiver of the radio waves, but its great advantage is that it determines the direction. The wave produces electrical action in the coil only when it is placed in the line of the advancing wave. If it is rotated so that it lies across the line of the wave, no effect is produced. As one turns the coil, the received signal changes from a certain maximum loudness to a weaker and weaker and finally zero sound. From the position of the coil when the sound is thus reduced to zero, the line of direction of the wave may easily be determined. This simple apparatus was in constant use during the war to locate the position of enemy radio outfits in the trenches, on ships, in the air, and even under the ocean.

Among the numerous problems presented for solution in connection with the direction finder was that of the accuracy of its indications. Would the direction thus determined make it possible to aim a gun so as to destroy the transmitting station? Was it sufficient to permit replacing the magnetic compass on a ship by a direction finder? (Incidentally, this use of the radio direction finder in navigation has led to the name generally adopted among naval and flying men, the "radio compass.") Another important practical problem was the determination of the abso-

lute direction of the transmitted wave. That is, could the direction finder determine not only the line of transmission of the wave but also from which of the two possible directions along that line the wave came? Other questions were: What was the best detecting apparatus to use with the direction finder? How did it compare with an antenna of a given size in the receiving of weak signals? Could this kind of aerial be used not only for receiving but for transmitting radio waves?

From the work done at the Bureau of Standards upon these and similar practical problems, it was found that direction could be determined to about 1°. This showed that the device could be used to prevent the interference of radio waves. That is, it became possible to receive the particular wave desired and exclude others. By turning the direction finder the waves from any particular direction may be excluded, and a wave from any other direction may be received without interference.

The indications of the direction finder are affected by its surroundings. A careful study of this subject was made, and it was found that metallic objects, such as a tower, bridge, or trolley wire cause very large errors of direction, since currents produced in these structures by the waves affect the direction finder. (Fig. 23.) Nonmetallic objects, such as a tree or bank of earth, have smaller effects. The effects of the surroundings can be corrected for if the direction finder remains fixed relative to the surroundings.

It was found that when very long radio waves are used their direction varies with time, especially at night. With the relatively short waves used on ships and in military operations, however, the variations are negligible.

One of the applications of the direction finder to navigation developed by the Bureau is its use in fog signaling. (Fig. 24.) The lighthouse lamp, made useless by a heavy fog, can be supplemented by a radio system, consisting of automatic apparatus for transmitting radio waves as regular signals at definite intervals. A ship equipped with a very simple radio direction finder can easily steer toward the lighthouse or determine its location.

Coil Aerial as Transmitting and Receiving Device

The simple coil aerial used as a direction finder was carefully investigated in comparison with the ordinary large antenna as a radiator and receiver of radio waves. It is in general not as powerful as the large antenna, but when a sensitive amplifier is used with the receiving apparatus the coil aerial is sufficiently powerful

for many classes of radio communication. The coil is used in series with a condenser, and to this simplest type of radio circuit is connected the generating or detecting apparatus, no connection to the ground being necessary. On account of the small size of the coil aerial, the complete radio outfit may be contained and used in an ordinary room. The coil aerial has advantages over the ordinary form of antenna for certain applications, as in the submarine work described in a subsequent paragraph.

A study of the principles of action of the coil aerial and the ordinary antenna led to the development of transmission formulas by which it is possible to calculate the current produced in the receiving apparatus for any distance from the transmitting station. The formulas have been verified by experiment. Laboratory studies were made of the design and electrical properties of coil aerials, thus leading to a knowledge of the best way to construct such an aerial for any particular purpose.

In field tests with the coil aerial it was found to have directional properties as a transmitting as well as a receiving device. That is, it transmits more intense waves parallel to its plane than at 90° to it. This valuable characteristic, together with the facts that more current can be gotten into it and that it can emit a narrower band of wave lengths than the ordinary elevated antenna, makes it valuable for certain applications, but its relative lack of power precludes its general use as a transmitting aerial. When used as a receiving device, it will pick up waves coming from a source a surprising distance away. By the use of exceedingly sensitive amplifiers, with an aerial consisting merely of a few turns of wire located inside an ordinary room, it is easy to receive in Washington signals transmitted from Germany or from the Pacific coast of the United States.

Submarine Radio Signaling

It was generally believed that radio communication could not be carried on below the surface of the ocean, since the water was thought to be so good a conductor as to be impenetrable by the radio waves. In the navies of this and other countries experiments had failed to develop a successful radio system for use under water. Nevertheless, the Bureau investigated the coil aerial as a possible solution of this problem.

In November, 1917, the Bureau of Standards placed a direction finder coil under water and received signals virtually as good as with the coil in the air. Additional experiments with the use of

the apparatus on a submerged submarine soon followed. Permis sion was secured from the Navy Department to make experiment at the submarine base, and after experimental work on sub marines had been conducted for several months very simple bu effective radio apparatus was developed.

The essential part of the apparatus is the antenna, of the co or loop type, consisting of a single turn of wire, heavily insulatec its circuit being completed by grounding to the metal hull of th submarine. On June 20, 1918, with every part of the submarin and its equipment submerged, signals transmitted from German were received in the submarine. Signals from Paris, Rome, an California were received with equal ease. Furthermore, the appa ratus was found to be a satisfactory direction finder just as whe used in air.

It was later found possible not only to receive but to transm radio messages when the submarine was totally submerge Transmission can not be carried on over very great distances, bu it is possible for a ship and a submerged submarine to exchang recognition signals. This is the only thoroughly successful syster that has been developed for communicating with submerge submarines, and the Navy has equipped a number of submarine with it, as shown in Fig. 25.

Signaling System for Airplane Landing

The radio direction finder is very useful to the aviator. Th magnetic compass and other instruments to assist him in steerin his course are affected by the rapid changes of motion of the ai plane and do not give him reliable information about his locatio with respect to a known point on the ground. By using the rad compass, he can steer toward his landing field, but a need was fe for a device which would supplement the radio compass by tellin the pilot when he was exactly over the landing field even in fo or darkness. The need for this had been felt particularly in th Air Mail Service of the Post Office Department.

A localized signaling system which fulfills the above requiremen has been worked out as a result of the Bureau's experiment Either of two methods may be used. In one, a large coil of wi consisting of one or a very few turns with a length of about 10 feet on a side is laid on the landing field. This coil carries sever amperes of alternating current of about 500 cycles per secon Magnetic induction from this coil extends over the space above th landing field, and produces a signal in telephone receivers connecte

FIG. 25.—*United States submarine equipped with coil antenna*

By this means the submarine can send and receive radio messages even when totally submerged. The system of submarine radio transmission developed at the Bureau has been applied to several vessels by the Navy Department

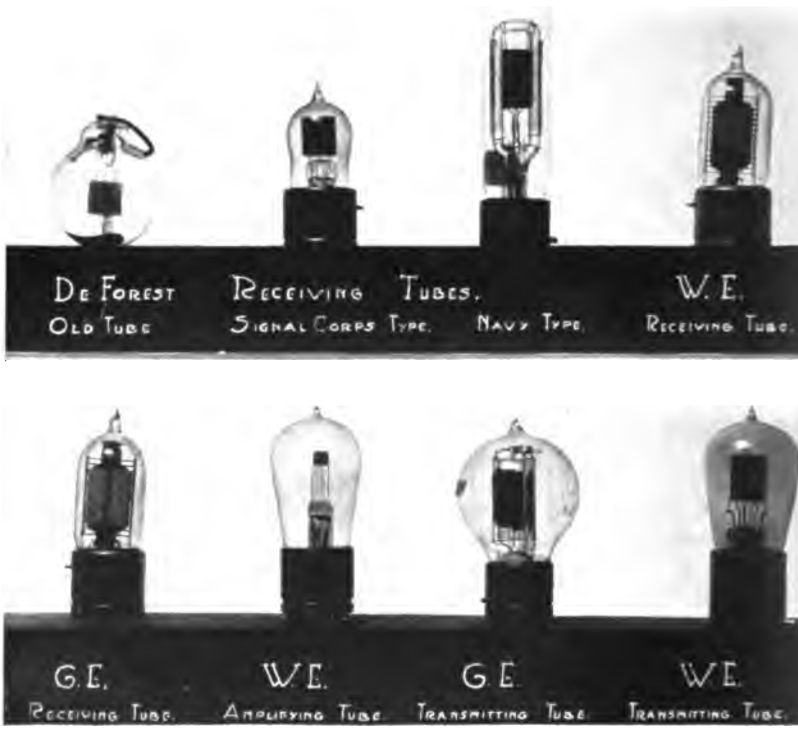

FIG. 26.—*Numerous forms of electron tubes*

This little device has revolutionized radio communication, has made possible radio telephony, and has aided in securing satisfactory multiplex wire telephony where as many as five connections are possible over one pair of wires

to a coil of wire on the airplane. The aviator hears the signal only when he is over the landing field. In the second method the result is produced by the use of specially constructed coils of much smaller size on the landing field, employing radio-frequency current.

Satisfactory signals are heard by the aviator at distances up to a mile above the field. The advantage of this system is not alone the actual utility to the aviator, but also the added sense of security against his enemy, fog.

Electron Tubes

The use of electron tubes was practically unknown to the military forces of the United States prior to 1917. All of the radio apparatus then used was of the damped-wave type. The development of military radio equipment employing electron tubes was given the needed impetus by the visit of the French Scientific Mission in the spring of 1917, since they brought with them, and exhibited at the Bureau of Standards, a great variety of equipments for radio communication which had been developed around the electron tube as the essential element.

The three-electrode electron tube is a simple device, known by a great many names, such as vacuum tube, audion, valve, lamp, thermionic bulb, triode, valve relay, etc. It looks much like an ordinary incandescent lamp bulb (Fig. 26), but has in addition to the hot filament two other metal structures, a simple wire grid and a metal plate or cylinder. The operation of this device depends upon the fact that every hot object is continuously giving off small particles of electricity, called electrons. Some of the electrons emitted from the hot filament go to the metal plate, and this flow of electrons constitutes an electric current. This electric current can be influenced or controlled by the flow of electrons to the metal grid. This control of one electric current by another very small electric current makes it possible to use the tube as an electric relay or amplifier and for many other purposes. A simple description of the fundamental theory of operation of the electron tube is given in Circular No. 74 of the Bureau of Standards, "Radio Instruments and Measurements," pages 200 to 215. This device was invented less than 10 years ago, and most of its development has been accomplished during the war. It is a remarkable instrument if only the variety of its uses is considered. Thus it serves as the detector of radio waves, as a very powerful amplifier of radio or any other electrical currents, as a generator or producer

of radio waves, and as the means for converting speech into a modulated radio wave which can be again changed into speech by a receiving radioapparatus. The reader will readily see that these important applications justify the most extensive and profound research, development, and application. Thus the principal work of the great New Jersey radio laboratories of the Signal Corps was the development of apparatus using these electron tubes. Certain research work and the standardizing of tubes and methods of testing were carried on by the Bureau of Standards. The principles of the operating and functioning of the tubes are, by contrast with the structure of the tubes themselves, complicated and difficult to determine. When one considers the extensive applications of these devices which have already been made, it seems strange that so little is known regarding the principles of their operation.

The importance of electron tubes in military work is apparent from the fact that for the American Armies alone 25 000 tubes were made each week. These devices have revolutionized all branches of radio and have produced many advantages for which investigators have sought in vain for years. Electron tubes have many applications outside of radio, as, for instance, their application to wire telephony, where they make possible five simultaneous conversations over one pair of wires. On account of their great sensitiveness as receiving devices, radio apparatus can be made very compact. These devices must be credited with a considerable share in the achievement mentioned above in describing direction finders, namely, the receiving of messages from a distance of thousands of miles with a small apparatus contained in an ordinary room. In fact, apparatus capable of concealment about a person's clothing may now be constructed by which one can receive the radio messages which are passing through space.

The electron tube has made communication between airplanes successful. Obviously, airplane apparatus must be extremely light in weight, and this is possible with the very sensitive electron tubes. Airplane pilots can now talk to one another, using apparatus that adds only a few pounds to the weight of the machine. Not only can the communication be carried on from one airplane to another and from an airplane to a ground radio set, but the apparatus can be connected to the ordinary telephone lines. The radio telephone upon which the above apparatus is based was brought by the French Scientific Mission to this country in

1917. Improvements in many points have been made since that time and have rendered the apparatus more reliable and effective.

On account of the Bureau of Standards' work on the characteristics of tubes, amplifiers, and other electron-tube apparatus, and on methods of measuring their constants and characteristics, the Signal Corps requested the Bureau to take over the general work of electron-tube standardization. The work included the measurement of numerous characteristics of tubes in order to check results obtained by field inspectors, a study of experimental tubes under development by the various companies, and of the methods of testing tubes in the field and in the laboratory, a determination of the causes of behavior of power tubes in various circuits, and a study of various amplifier circuits. The Signal Corps was assisted in its inspection work by instructing a number of electron-tube inspectors who were detailed to the Bureau of Standards for that purpose and were given instructions for a period of six weeks in the methods of testing tubes.

Special Military Researches on Electron Tubes

A number of rather extensive researches were carried on following a definite program laid out by the Bureau after receiving a specific statement of the problem from the Signal Corps. One of these was on the efficiency of electron-tube generators of high-frequency current as affected by the production of harmonics. Investigation had shown that practically all the generating circuits used in Signal Corps apparatus were heavily loaded with harmonics, so that the output hot-wire ammeter reading gave no indication of the useful power output which is all contained in the fundamental frequency. This was investigated both by measurements of current in tuned circuits and by direct observation of the wave forms in the cathode-ray oscillograph. A complete solution of the problem was obtained. The principles were developed by which the amount and effects of the harmonics may be determined, and by which apparatus can be so designed as to reduce them.

A critical study was made of the Signal Corps testing sets for receiving tubes. These sets had served well as factory testing sets, but it was recommended that the Bureau make a critical study of them, looking toward improvements in design, practice, or method, and having as particular objects increased uniformity of the inspected product and decreased difficulty of manufacture. It was found that a number of improvements could readily be

made in the amplification and in the detector test sets. It wa shown that the generator test set did not make a real test of th generating properties of a tube, as it would be difficult to find a tube which would not oscillate in this set. Furthermore, it wa easy for the operator to connect up the set so as to change it indications radically. The following suggestions were made: (1 A circuit which really tests the generating properties and which i similar to actual receiving circuits should be used, and (2) a dif ferent method of indicating the presence of generated curren should be employed.

In using receiving tubes as high-frequency amplifiers the Signa Corps had noticed that the input impedance of the tube, particu larly that part contributed by the capacity of the grid to the othe electrodes, seemed to be a function of the electrical constants o the plate circuit. A further knowledge of this was very desirabl and the Signal Corps recommended that the Bureau make a experimental study of the subject, using in particular the VT- tube. A complete solution of the problem was attained by theoretical investigation, checked experimentally. It was foun that the input impedance of a tube can be represented as a serie resistance and capacity, the values of which depend in a definit and determinable manner upon the electrical characteristics o the plate circuit and the capacities between the tube electrode

At the request of the Bureau of Steam Engineering, Nav Department, a study was made of the use of high-power thre electrode tubes for producing power at radio frequencies, pa ticularly for radio telephony. For supplying the direct-curre power to the tubes without use of commercial high-voltage direc current generators, a rectification system was developed, usin three-electrode tubes in place of the two-electrode tubes usuall used as rectifiers. It was found that the third electrode, or gri could be used either for smoothing out the pulsation in the outpu current or for increasing the efficiency of rectification, but not fo both at the same time. Accordingly, attention was directe especially to the use of the grid control for increasing the efficiency while the desired smoothing out of pulsation was obtained b other methods. For the latter purpose the output load wa shunted with a condenser and inductance in series, tuned to th principal frequency to be eliminated. For converting the direct current power thus obtained into radio-frequency power, a stud was made of the use of large power tubes as radio-frequency am plifiers. In this system the tube or set of tubes operates into

high-power resonant circuit or antenna, while the grid alternating voltage is supplied from an independent low-power resonant circuit which is excited by a low-power electron-tube radio telephone set. This radio-frequency power amplifier was found to possess many advantages, especially in simplifying the design of the high-power output circuit, and in placing most of the complicated apparatus in the auxiliary low-power radio telephone set.

Radio Measurements and Tests

An interesting portion of the work consisted in development along the lines of technical measurement. The basic facts, the knowledge of which has made possible the improvements above described, could never have been discovered without careful measurements of the phenomena which take place in connection with the use of high-frequency radio currents. These measurements are far more complicated than most of the ones with which we are familiar. In this matter of measurements the Bureau naturally is the recognized leader in the country, and radio measurements in particular have been very highly developed by its laboratories during the last few years.

The beginning of the work for the military forces was contemporaneous with improvements in radio measurements made possible by the use of the electron tube. Tubes were put into service in the laboratory as a source of current for measurement purposes, particularly as generators of very steady high-frequency currents, which have made possible measurements to an accuracy of 1 or 2 per cent, whereas 5 or 10 per cent has been the previous limit. This greater accuracy of measurement made it possible to develop more accurate radio instruments, and thus called for the development of special methods of measuring, special means for avoiding small errors in the measurements, and special measuring instruments. Standards for the important measurements were established. The theory of radio measurements was studied extensively in the Bureau's laboratory, and the results of this work were made available to the Army, Navy, and manufacturers through special laboratory reports and printed publications.

A great deal of the measurement work was concerned with the fundamental components of all radio circuits, capacity, inductance, and resistance. A typical instrument set-up for this work is shown in Fig. 27. The elimination of errors in the laboratory by carefully devised shields and other precautions was necessary. Apparatus for the production and measurement of large current

and high voltage at radio frequencies was developed. (Fig. 28
For the measurement of small current, thermoelements were use
while for the very small currents, such as those in a receiving antenn
electron tubes were employed. Special mention should be mad
of the employment of these tubes in a special method of comparin
the received with a locally produced signal. Numerous types
radio apparatus were designed, and this work made necessary a
extensive study of the inductance coil, one of the principal el
ments of every radio circuit. Electrically, a coil is a complicat
apparatus, and there has been no comprehensive information
its behavior in a radio circuit.

A number of tests of radio operating apparatus, such as tran
mitting sets and antennas, were made. A particularly interesti
one consisted in a complete test of a Signal Corps airplane radi
transmitting set known as type SCR–73. It was modeled on
French set, and comprised a self-excited, 900-cycle generat
wind-driven by a small propeller, and a radio set of the spark typ
Provision was made for rapid change to any of 16 wave lengths
to any of 6 signal pitches, for the purpose of reducing interferen
with other transmitting sets. The tests included characteris
curves and oscillograms of voltage and current from the generat
power output and tests of the self-excitation and other featu
of the generator, study of capacity to produce best spark tone a
maximum quenching action, nature of wave radiated, and gene
criticism of design.

Among other interesting tests was that of a novel type
quenched-gap transmitting set. The operation of special featu
of the set was clearly revealed by the use of the cathode-r
oscillograph. The determination of the constants and behavi
of a submerged cable used as a receiving antenna formed anoth
investigation. Quite a number of tests were conducted a
studies made of the design of wave meters used as radio measuri
instruments. Detailed comparative studies were made of t
design of commercial, Signal Corps, and French wave meters, a
the Bureau's experience in measurements and design enabled
to suggest improvements. One of the tests of wave meters i
tended for field or air use was a shaking test, in which was dete
mined the effect on the instrument caused by placing it in app
ratus which simulated the vibrations of an airplane.

The routine tests from May 1, 1917, to June 30, 1919, includ
467 electron tubes, 279 decrimeters, 78 wave meters, 40 conde
sers, 39 inductors, 13 ammeters.

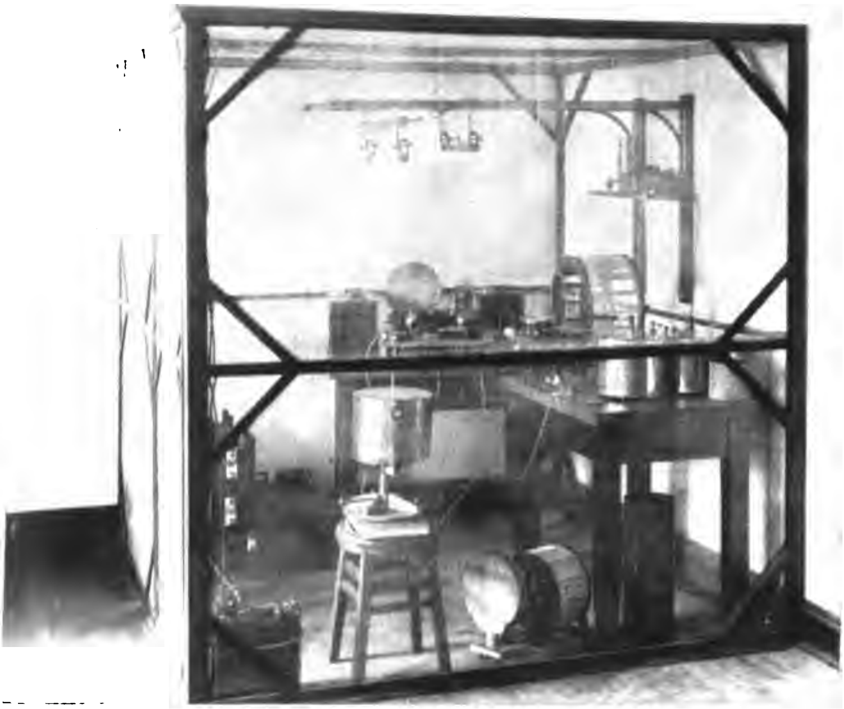

FIG. 27.—*Apparatus for measuring the properties of inductance coils used in radio transmitting and receiving sets*

The instruments are inclosed within a cage of galvanized wire screening in order to avoid interference by waves from near-by transmitting or generating sets

FIG. 28.—*Apparatus for generating high voltages at radio frequencies used in the study of the radio properties of insulating materials for radio apparatus*

FIG. 29.- *Apparatus for testing self-luminous dials*

By means of this equipment it is possible to determine whether a sample possesses the requisit brightness

Cathode-Ray Oscillograph

There is no mechanical instrument which can follow the exceedingly rapid alternations of the current used in radio circuits. The only way this can be done is by the use of a stream of electrical particles, as in the cathode-ray oscillograph. In this instrument a beam of cathode rays is deflected by the currents, and the motion of the beam is made visible on a fluorescent screen. Thus the wave form of radio current can be seen, and the phase relations of currents and voltages in radio circuits can be directly determined.

Two general types of cathode-ray tube have been used at the Bureau of Standards, those using a high voltage to cause emission of a stream of electrons from the plane cathode of metal and those having a cathode consisting of a heated filament from which the electron emission is spontaneous. Tubes of the former type are suitable for the measurement of currents of the order of magnitude of 1 ampere. The hot-cathode tube is suitable for measuring the electron currents obtained in three-electrode electron tubes, which are of the order of magnitude of 0.05 ampere.

Oscillograms were made with these tubes as a part of the tests performed upon radio transmitters submitted to the Bureau of Standards. The quenching action of different spark gaps is determined directly by passing the gap currents through suitable deflecting coils placed around the tube. A time axis perpendicular to the current deflection thus produced is provided by connecting the electrostatic deflecting plates across the capacity in the closed oscillatory circuit.

The cathode-ray oscillograph was also used in the investigation of the harmonics produced in antenna circuits by electron-tube generators. Dynamic characteristic curves are obtained for a given generator by impressing the grid voltage upon the deflecting plates and allowing the electron currents to flow through the deflecting coils. The wave forms of the antenna currents are determined by providing a sinusoidal time axis from a separate generator tuned to a lower frequency, of which the frequency of the antenna current is a suitable multiple.

The combination of an electron-tube generator, which is capable of furnishing currents at any frequency up to that corresponding to a wave length of a few centimeters, with a cathode-ray tube having a slow-moving electron stream, whose deflections are closely proportional to the instantaneous values of these currents, offered an opportunity for much profitable research. By the use of one of these tubes a study has been made of the characteristics of electron tubes under actual operating conditions.

Insulating Materials

The work which was in progress at the Bureau of Standards o insulating materials during the war included the measurement o all the properties which are of importance in determining th value of the materials for radio apparatus. Both in regard to th number of properties thus investigated and the number of material the investigation was a comprehensive one. The work was mainl on the class of materials most widely used in radio equipment, know as the phenol or bakelite type. Much of the work of measureme was carried out by other sections of the Bureau, the only mea urements made in the radio laboratory being those involving th electrical properties at radio frequencies. While a wide variet of electrical and mechanical properties of the materials were mea ured, the object principally in mind was the determination of th suitability of the materials for radio uses.

The work involved in this investigation can not be appreciat without an understanding of the nature of the materials. The all contain a phenol resin or varnish of the general type invent by Dr. Bakeland and may be divided into two general classes, t laminated and the moulded materials.

It was fortunately possible to make the measurements of ele trical, mechanical, and thermal properties on the actual sheets material as regularly supplied for commercial use. Consequentl the data obtained should be directly applicable, as it was n necessary to manufacture samples especially for test purpos Thus, for instance, for the radio measurements condensers we made up using an actual slab of material such as is employed the construction of apparatus; that is, regular stock as furnish by the manufacturer. This is a far better way to conduct a te than by making up a special condenser from specially prepar thin sheets of the material.

Mechanical properties which were measured included tens strength, transverse strength, modulus of elasticity, permane warping, brittleness, hardness, density, and moisture absorptio The thermal tests included thermal expansivity, a little work the effect of temperature on hardness, and some work on the effe of temperature on the disintegration of the material by carbo ization, etc. The electrical properties included volume resistivit surface resistivity, power factor, dielectric constant, and the effe of high voltage at radio frequencies.

Investigations have been made of the effects of voltage at rad frequencies upon insulating materials. This work has required t

development of entirely new apparatus for the production of constant high-frequency voltages, for their application to insulating specimens, and for their measurement. Essentially, the method consists in placing a sample of material in a radio circuit with electrodes upon its surface in parallel with a condenser and measuring the voltage required to produce certain effects, such as the appearance of corona, flash over, and also puncture of the material. The flash over and puncture voltages are of very different magnitude at high frequencies as compared with other values at low frequency for the following reasons: Very much lower voltages produce these effects at radio frequencies than at low frequencies, because the dielectric carries a considerable dielectric current. This current heats the specimen by virtue of the absorption phenomenon or dielectric loss in the material and soon raises the temperature to a point where breakdown occurs. The effect is then not a puncture or rupture of the low-frequency type at all, so that instead of hundreds of thousands of volts being required to break down or flash over a specimen, 10 000 volts more commonly suffices.

Measurements of the various properties which have been enumerated were made upon several hundred samples of material representing various grades and thicknesses of the standard products. These were mainly laminated materials, but some of the work has been upon the molded phenolic materials. In general, the more expensive grades are superior in their electrical properties. The reverse is true in regard to mechanical strength. For example, the cheaper materials have higher tensile strength than the more expensive. The expense of the materials is usually determined by the percentage of phenol varnish to paper, the more expensive materials having a larger percentage of varnish. The thermal properties do not in general furnish any means of differentiating between the several materials. Above 50° C the variation of dimensions with temperature is not reversible, and many peculiar expansion and retraction effects have been noticed upon raising and lowering the temperature. All the phenol materials have smaller coefficients of expansion than hard rubber. The insulating materials of the phenol type came into use largely because a substitute for hard rubber was wanted, the value of the latter material for electrical apparatus arising from the fact that it is easily machined, has very small power loss or phase difference, and very high puncture voltage at radio frequencies. It has, however, certain other objectionable features; thus, it shrinks,

warps, is brittle, deteriorates in sunlight, and has high therma expansivity.

An interesting result which was observed in the power-facto measurements was an apparent increase of power factor in particular sample of over 100 per cent after a lapse of time of si months. Upon investigation this change was found to be a actual change, and by a baking process the phase difference wa brought down again to approximately the value of six month before. This and similar experiments on other materials sug gested that the absorption of moisture from the atmospher changes the properties of these insulators.

Permanent Crystal Detectors

In March, 1918, the Signal Corps submitted a suggestion for crystal detector having a permanent contact and possessing hig sensitivity. The plan was to secure on the surface of the crysta by alternating-current electrolysis, needlelike deposits, perhap one-half mm high, and making a permanent soldered contact t a number of these needles. It was thought that the addition contacts would give increased sensitivity, besides possessing th advantage of a permanent contact not disturbed by ordinar mechanical jars. This was desirable for field work, as a cryst detector was needed having a permanent contact which could b used in the field without the necessity of continually resetting th contact wire on a sensitive spot of the crystal.

Experimental work was carried out along the suggested lin by the Bureau. It was found that deposits could be secured b electrolysis using a 60-cycle alternating current of the order 50 milliamperes, and that in some cases deposits secured on ca borundum were sensitive. It was also found that no advanta could be practically attained by using a number of contacts i parallel, and that, in general, the signal obtained using two co tacts in parallel was less than that obtained using alone the mo sensitive one of the two contacts. Difficulty was met in attemp ing to secure sensitive deposits on galena, because most electr lytes seriously affected the sensitiveness of the galena as a d tector. Since galena is one of the most sensitive crystal detector it was very desirable that a permanent-contact galena detect should be obtained, if possible.

Later attempts were made to secure, electrolytically, deposit on a number of different crystals, using a radio-frequency curren of 150 to 200 milliamperes. Some sensitive deposits were secure in this way, but they were not satisfactory, as they were n

adherent. In the work at radio frequency it was shown that the sensitiveness of a deposit is dependent on the failure to obtain a perfect contact with the crystal surface, and that really adherent deposits are practically never sensitive. Work with direct-current electrolysis also served to confirm the conclusion that sensitiveness of a metallic deposit depends on failure to make perfect contact with the crystal surface.

As a possible means of securing permanent contact, soldering was attempted, but without success, except in the case of molybdenite. No flux was found which would cause the solder to adhere either to galena or silicon. Both arc and spark welding were tried. Wires as fine as No. 40 were welded to galena, silicon, iron pyrites, and molybdenite by these methods, but in no instance was the welded contact sensitive. Since in welding the surface was melted and the surface immediately surrounding the weld, which had been melted in the process, was found to be insensitive, this method was not successful.

A fairly satisfactory detector was constructed by making a contact between a slightly hollowed surface of Wood's metal and the sharp point or edge of a galena crystal, the whole being inclosed in paraffin or sealing wax. The chief difficulty encountered was due to alternation in the contact caused by expansion of the wax with change of temperature. Some experimental detectors so made remained fairly sensitive for several weeks, but after a few months were usually found to be much less sensitive.

Two general conclusions were drawn as a result of these investigations: With the less sensitive crystals, such as carborundum and molybdenite, plated-contact detectors of fair sensitiveness can be made, but this is no practical gain, since these crystals have previously been in use with fixed contacts. With the more sensitive crystals, such as galena and silicon, the only method which gives promise of success is that of a mechanically maintained high-resistance contact.

Peace-Time Value of Work

The radio work carried out during the war presents a conspicuous example of scientific advancement of permanent value. It has been estimated that in two years of war the progress in radio was equal to that in 10 ordinary years. The work of the Bureau contributed to the progress made upon the electron tube, the direction finder, control of radio waves, radio measurements and design, submarine signaling, airplane communication, and radio instruction. Each of these, with the possible exception of

submarine signaling, has positive value in the normal pursui of peace.

As a result of the research work during the war, the electro tube was developed from an unstable, experimental device, use largely by amateur radio enthusiasts, to a dependable instrume of standardized operating characteristics, produced on a com mercial scale and used in large quantities. Besides increasin greatly the effectiveness of radio-receiving apparatus, it is use also as a generator of alternating current of any frequency from to 100 000 000. Reliable long-distance wire telephony has bee made possible by the electron tube; through its aid many tel phone conversations are carried on over one pair of wires. It used in the construction of amplifiers which magnify very feeb currents or signals hundreds of times. In consequence, rad antennas can be reduced to very small dimensions and the ran of radio communication greatly extended. Music, as well as th voice, is readily transmitted without wires, even across the ocea A symphony concert can readily be given at one point and sent forth by radio so that it can be received anywhere in th United States.

The direction finder has been developed into a very convenie and portable apparatus. It replaces the antenna for receivi radio waves and determines the direction of the transmitting st tion. It is useful in determining the location of radio stations, in the work of Government inspectors when violators of the rad laws are sought. It is of the greatest value as a safety device either airplanes or ships in fog or other perilous circumstance Following the end of the war the Bureau of Lighthouses and th Bureau of Standards took up actively the development of a fo signaling system involving the use of the direction finder. Thu aided, a ship can steer toward a lighthouse or determine its pos tion during the heaviest fog.

The improvements in design of radio apparatus and the advan in methods of radio measurement have increased the efficiency instruments and equipment. Progress in the understanding an control of radio waves has increased the certainty with which th range of communication of any radio set can be calculated. Th textbooks and other material prepared for the training of Sign Corps men in radio have been found useful in universities and othe institutions.

One of the incontestable benefits which has been salvaged from the war is the application of radio to airplane communication. I

the future of aerial navigation, as in policing the air, radio will play an important part. The electron tube has made possible conversation between airplanes and the ground, the direction finder is the compass of the aviator, and radio methods supply the signals by which a landing may be made in fog or darkness. The ordinary wire telephone can now be connected to a radio system, so that conversation between the ordinary city telephone and an airplane is possible. Radio supplements the older systems of communication, and no spot on the earth or in the air is too remote for it to reach.

RADIOMETRY

Researches

The following paragraphs summarize the most important investigations in Radiometry which had a direct military application:

Radiant Power Life Tests of Quartz-Mercury Vapor Lamps

This subject is treated under the heading "Aircraft Materials."

Optical Properties of Balloon Fabrics

This subject is treated under the heading "Aircraft Materials."

Photoelectric Sensitivity of Molybdenite and Various Other Substances

This subject is treated under the heading "Invisible Signaling."

Amplification of Bolometer Current for Signaling Purposes

This subject is treated under the heading "Invisible Signaling."

Infra-red Transmission Spectra of Various Substances

The spectral transmission of various substances, including special glasses, colored fluorite, salts in solution, etc., was determined. The data were published in Scientific Paper No. 325.

Some of the substances examined (including material submitted for official tests) were found useful in a device used for secret signaling by means of infra-red rays. As a result of this investigation, a prominent glass factory improved the infra-red transmission of a red glass by eliminating the iron impurities which cause an absorption band at 1μ.

Protection of Moving-Picture Film from Heat of Lamp

In certain military work it was desired to stop the movement of the picture film in order to make an examination of the details of a single picture projected upon a screen.

As ordinarily used, the moving-picture film is protected from injury by the intense infra-red rays from the lamp because it is

exposed to these rays for only a very short period of time. Appl ing the information obtained in the foregoing and in a previo investigation, the intensity of the infra-red rays was great reduced by using a dilute (1 to 2 per cent) solution of cupric chl ride, which absorbs but little of the visible spectrum, while bei practically opaque to infra-red rays.

Glasses for Protecting the Eyes from Injurious Radiations

Information on the protective properties of glasses used oxyacetylene cutting and welding is very important. That tl Bureau's efforts in obtaining such data are appreciated by man facturers is attested by the fact that the first issue of its techn logic paper on this subject was exhausted within three mont after publication, one shipbuilding firm calling for almost a hundr copies.

In addition to research work on this subject, quite a number official tests were made on the eye-protective properties of glass submitted by dealers and by the construction departments of t navy yards at Washington and Philadelphia.

During the past year extensive new data were obtained on t ultra-violet and infra-red radiations transmitted by various glass used for spectacles. The sources of radiation used were typic of those to which one is exposed in occupational pursuits. F example, the quartz-mercury vapor lamp and the iron (magnesit arc used in these tests were representative of the sources of e tremely intense ultra-violet radiation, while the gas-filled tungst lamp and the sun represented high intensities in the visible a infra-red spectrum. These new data were published in a revis and enlarged (the third) edition of Technologic Paper No. 9 "Glasses for Protecting the Eyes from Injurious Radiations."

Reflecting Power of Stellite and Magnalium

Stellite is an alloy of chromium, cobalt, and molydbenum. takes a high polish and appears to be quite permanent in air. reflects from 60 to 65 per cent of the visible rays. (See Scienti Paper No. 308.) From a military standpoint the use of stelli was under consideration for reflecting mirrors in periscopes a range finders.

In response to a request from the Chief Signal Officer, W Department, for information on the reflecting power of magnaliu (aluminum-magnesium alloy) mirrors, data were obtained samples prepared by the division of metallurgy.

It was found that the reflecting power of the best samples of magnalium increases uniformly from about 85 per cent in the blue to 90 per cent in the red. The average sample would probably reflect 85 per cent depending upon the polish.

Instruments and Methods of Radiometry

While the investigations of thermopiles, photoelectric cells, etc., were not undertaken with a view to direct military application, it is known that the method of construction and general technique developed in this Bureau were useful to others who had military problems under investigation. For exemple, on the basis of Scientific Papers Nos. 188, 229, 282, and 319, the thermopiles were constructed for the purpose of detecting the presence of airplanes, etc., at night by the heat emitted by the engines. Apparatus was sent to France for testing out this device.

Thermopiles made by the Bureau were lent for measuring the intensity of searchlights. One thermopile was lent to the United States Naval Experimental Station to determine its usefulness in detecting ships at night by the heat emitted from the smokestacks.

Reports of the official tests on this device made by the National Research Council were very favorable, and it was suggested that further work be done.

Lacquers for Protecting Tarnishable Metallic Surfaces

Owing to the scarcity of optical glass it was desirable to find suitable metal mirrors as a substitute for lenses used in range finders, periscopes, airplane cameras, searchlights, etc. Silver-on-glass mirrors are easily prepared, but a lacquer covering is required to prevent the silver from tarnishing.

From the experience gained in this laboratory, it appears that unlacquered mirrors which are inclosed to the extent afforded in a camera will not tarnish appreciably in one to two years. This tarnish is quite soluble and easily removed by dipping the mirror in water or by polishing it with soft chamois skin and opticians' rouge.

Tests were made of water-white silver lacquers, such as "Albaline," "Zapon," etc. They were diluted, filtered, and poured upon the freshly polished silver. The excess material was allowed to drain off and then the mirror placed in a level position to dry.

Theoretically, a lacquered-silver surface should reflect almost as much light as does an unlacquered surface. In practice, however, the reflecting power was found to vary greatly with the condition of the lacquered surface. A newly lacquered silver

mirror reflects from 70 to 75 per cent of the incident yellow ligh while in the red it reflects from 80 to 85 per cent, depending upo the homogeneity of the lacquer. Uncoated or bare silver reflec from 90 to 95 per cent of these rays.

In the near infra-red, where nitrocellulose is free from absor tion bands, the reflecting power increased gradually to about per cent.

For reflecting heat rays of long wave lengths, which are absorbe by the lacquer, mirrors of nickel or gold (which reflect 95 p cent) should be used.

At the request of the General Engineer Depot of the W Department for information on lacquers suitable for protecti metal searchlight mirrors an examination was made of the effe of ultra-violet light upon the various lacquers commercial available.

It was found that the photochemical action of ultra-viol light such as obtains in a searchlight liberates sulphides a nitrous oxides which may be present as impurities or which a constituents of the lacquer and which then attack the silver. a result the silver under the lacquer, following exposure to carbon arc or a quartz-mercury vapor lamp, is quickly turn brown in color. For example, after 6 hours' exposure at a di tance of 0.5 from a small (15-ampere) carbon arc a lacquer silver-on-glass mirror had changed to a brownish color, whi strongly absorbed the yellow, green, and violet lights. As result the reflecting power of the lacquered mirror for wav length $\lambda = 0.55\mu$ (greenish yellow) was decreased from 74 p cent to 68 per cent. Similarly, at $\lambda = 0.65\mu$ (orange-red colo the reflecting power was decreased from 82 to 79 per cent, a at wave length $\lambda = 0.7\mu$ (red light) the reflectivity was decrease from 85 per cent to 83 per cent. In a powerful searchlight su a lacquered silver mirror would be injured in a few hours. bare nickel-plated glass mirror would be just as efficient. gold mirror would be more satisfactory.

Specifications and Methods of Test

In connection with the preparation of standards for head-an eye protection which is being carried out by the Bureau in co junction with the safety engineers of Federal industrial esta lishments considerable experimental work was done on the pr tective properties of glasses already in use in the navy yard This was done for the purpose of obtaining a glass of suitab

transparency for oxyacetylene cutting and welding, and at the same time of providing ample protection against injurious radiations. Specifications were then drawn defining the maximum transmission of injurious radiations permissible, especially for infra-red rays. Sources of radiation which are readily obtained by manufacturers were also investigated. A gas-filled tungsten lamp was found suitable for testing the protective properties of glasses for infra-red or so-called heat rays.

For the General Engineer Depot tests were made and specifications written for glasses for soldiers and engineers to provide protection against glare from snow, etc.

Conferences, Consultations, Etc.

Under this caption there are enumerated some of the military problems presented by Government bureaus and manufacturers. The subject most frequently presented related to thermal-radiodynamic devices for secret signaling, and for detecting submarines or battleships in a fog by the heat radiated from the smokestacks, etc. Many of the inquirers did not seem to realize that for radiations of wave lengths such as would be emitted by a smokestack water vapor is the most opaque substance known, and that, consequently, during a fog, when this sort of signaling device would be most needed, the radiations to be detected would be completely absorbed within a very short distance from the source. Many of the questions submitted were so impractical that it was easier to advise what not to do than to suggest improvements.

The selenium cell had its share of suggested applications, nearly all of which, as it turned out, seemed impractical. For example, in reply to inquiries from the Naval Proving Ground, Indian Head, Md., on the applicability of photoelectric devices (selenium cell) for registering the speed of projectiles, some laboratory tests were made which indicated that such devices are not sufficiently positive in action to use in such tests.

Another inquirer desired to obtain a series of photographic exposures at frequent intervals throughout the day, and wished to use the selenium cell (in some manner that he had not yet worked out) to regulate the diaphragm opening of a camera. The inapplicability of the selenium cell was indicated to him, and a series of tests was made which demonstrated the adaptability of the Callendar sunshine receiver and the sliding mechanism of the recorder to the actuation of the diaphragm opening of a camera. By connecting the diaphragm with the sliding arm of the recording mecha-

nism, the to-and-fro motion of the latter regulates the diaphragı opening of the camera, and hence the amount of light reaching th photographic plate.

Members of the National Research Council conferred on th applicability of the selenium cell as a means of communication fo airplanes, etc. The potassium photoelectric cell device describe elsewhere in this report was suggested as best adapted for suc signaling.

In reply to inquiries from the General Engineer Corps on th feasibility of using thermal radiations for destructive purposes, a for example, igniting a captive balloon, it was shown that te restrial sources of radiation were not powerful enough. Anothe inquirer thought sunlight could be used; but among other thing the method had not been thought out of producing the concav mirror 20 to 40 feet in diameter which would be required in orde to obtain sufficient intensity to ignite an object at a distance of to 5 miles.

To a manufacturer of quartz mercury vapor lamps, and to paper manufacturer using such lamps in fading tests, informatio and specific directions were given on making radiant power life tes of mercury vapor lamps, and their applicability in fading tests this kind.

The feasibility of testing toxic gases by radiometric instrumen was discussed with military officials from the Bureau of Mine and selenium cells made at the Bureau were provided for exper mental work in the development of tests for the presence these gases.

In response to a request from the National Research Counci a representative of the Bureau attended a conference at Columbi University, New York (August, 1918), at which were presented th results of experiments on the detection of various objects such a airplanes, human beings, etc., which give off a certain amount heat, by means of a thermopile (after this Bureau's constructio placed at the focus of a 2-foot concave mirror.

By invitation from the special board, a representative of th radiometry section demonstrated the Bureau's thermal radiody namic secret-signaling apparatus in September, 1918, at th naval experimental station, New London, Conn. In addition t the specific cases just cited, information was given on variou radiometric matters such as the reflective properties of meta useful in searchlights, etc.; the thermal radiodynamic signal ing devices; photo-electric substances; eye-protective glasses; th

constancy and methods of standardization of sources of ultra-violet radiations of high intensity; emissivity of paints to be used for preventing the heating of certain kinds of electrical machinery; construction of ironclad Thomson galvanometers; standard blackening of radiometer receivers; and various other radiometric questions having a military application.

Publications

The following recent publications in radiometry contain data which have a military application, though, of course, some of the earlier investigations were not undertaken with that specific end in view:

Technologic Paper No. 93 (3 ed., rev. and enlarged). Glasses for protecting the eyes from injurious radiations.

Scientific Paper No. 229. Various modifications of bismuth-silver thermopiles having a continuous absorbing surface.

Scientific Paper No. 282. Sensitivity and magnetic shielding tests of a Thomson galvanometer for use in radiometry.

Scientific Paper No. 300. Emissivity of straight and helical filaments for tungsten.

Scientific Paper No. 308. Reflecting power of tungsten and stellite.

Scientific Paper No. 319. Instruments and methods used in radiometry, III—the photo-electric cell and other selective radiometers.

Scientific Paper No. 322. Photo-electric sensitivity of bismuthinite and various other substances.

Scientific Paper No. 325. Spectroradiometric investigation of the transmission of various substances.

Scientific Paper No. 330. The decrease in ultra-violet and total radiation with usage of quartz-mercury vapor lamps.

Scientific Paper No. 338. Some optical and photo-electrical properties of molybdenite.

Scientific Paper No. 344. The spectral photo-electric sensitivity of silver sulphide and several other substances.

Thermal-Radiophonic Devices for Secret Signaling

This subject is treated under the heading "Invisible Signaling."

RADIUM

During the war self-luminous materials were very extensively used for the illumination of aircraft instruments of all kinds, of gunsights, of targets for indirect fire, of marching compasses, of watches, of navigation instruments; in short, they were used wherever an entirely self-contained light of low brightness was desired.

In determining the suitability of these materials for given purposes and in drawing specifications for their use numerous questions arose. Many of these questions related to points concerning which much misinformation existed, others to details that were easily and commonly overlooked, and others to features that

were but little understood. The answers to some were to be found scattered through the literature of physiological optics, of radioactivity, and of phosphorescence. The answers to others required a knowledge of the properties of commercial self-luminous materials. Up to June, 1917, no article treating of the properties of such materials had been published, and but two bearing directly upon (noncommercial) self-luminous materials were available. Nowhere was to be found in collected form information covering the many important practical points involved in the efficient use of these materials.

Early in 1916 the Bureau of Standards began an investigation of these materials to collect information concerning them and to study the problem of the precise measurement of their brightness. Suitable apparatus was constructed (Fig. 29) and a long series of measurements of many specimens obtained from different sources was begun in October, 1916; some of these materials are still under study. In the spring of 1917 a study of the various problems connected with their practical use was begun.

Consequently, when in the summer of 1917 these materials acquired a military importance, the Bureau was in a position to answer many of the questions that arose and to undertake the investigation of various problems that presented themselves from time to time. It soon became the recognized source of information on the subject.

The Bureau's war activities in this field embraced four distinct lines:

1. The furnishing of information and recommendations.

2. The investigation of specific problems.

3. The preparation and standardization of equipment for the factory testing of dials.

4. The routine precise measurement of the brightness of the markings on articles submitted for test.

Information and Recommendations

Information and recommendations were disseminated by means of six typed circulars, many letter reports, and numerous conferences with representatives of those branches of the Army and the Navy who were especially interested in the subject and with representatives of the companies manufacturing and applying these materials. Special reference should be made to the large number of conferences in the last half of 1917 between representatives of the Bureau and representatives of the National Research

Council and of the science and research division, Signal Corps, U. S. A.

A few of the questions that had to be answered and of the errors that had to be corrected will illustrate the nature of the information that was required.

1. Shall the dial plate be silvered? Dial plates illuminated before the summer of 1917 were frequently silvered. These dials present a very pleasing appearance by day and in total darkness, but under certain moonlight conditions the contrast between the dial plate and the markings is so slight that the markings can not be seen. The dial plate should be black.

2. It was commonly believed that the effective life of radium luminous materials is comparable to that of radium (radium is half disintegrated in 1760 years). Actually the effective life of these materials is relatively short.

3. It was urged that the material should be specified by its radium content. Actually a specification of the radium content is not sufficient to determine the brightness or life of the material.

4. It was suggested by some that a high brightness should be specified in order to insure a long life. While increasing the initial brightness does increase the effective life, the increase in cost is out of all proportion to the increase in life.

5. What is the effect of replacing the radium by other radioactive material?

6. Shall dry material or that mixed with varnish be used? How does the brightness differ in the two cases?

7. How soon after the material is made shall the illuminated article be inspected for acceptance?

8. Should the dial contain many marks or few?

9. What brightness is required? How does the brightness required vary with the size and style of the luminous markings?

10. Shall the luminous lines for rear sights be made very narrow? It was found that under working conditions the apparent width of luminous lines for rear sights is practically the same whether the line be 0.5 or 1.7 mm in width. Throughout this range the apparent width is about 5 or 6 mm. Hence very narrow lines, requiring brighter material, are desirable.

It was to answer and to furnish the information needed to enable one to discuss intelligently such questions as these that the six typed circulars were issued. They were rather hurriedly prepared to meet immediate needs, in some measure overlapped,

and were in no sense intended to be regarded as finished products They were issued in small editions and supplied to those most interested. They do not lend themselves to abstracting, but an idea of the ground covered may be indicated by the following table of contents:

RLC-1. Self-luminous materials containing radioactive excitants; a report from National Bureau of Standards, March 10, 1917; revised November 16, 1917. pp.17

General description of these materials; Properties of the phosphorescent base Properties of the radioactive excitants—Radium, Mesothorium, Radiothorium, Polonium; Growth and decay of brightness; Manufacturers, materials, prices; Applied material; Legibility; Specifications and testing.

RLC-2. Supplement to the preceding report, April 10, 1917. pp. 5.

This treats mainly of the life of dry material contained in tubes.

RLC-3. Specifications for self-luminous dials, pointers, scales, etc. Proposed t science and research division, Signal Corps, U. S. A., September 24, 1917. pp. 3 (Superseded by RLC-6.)

RLC-4. Notes and suggestions concerning luminous instruments, November 16 1917. pp. 6.

Size of characters, Spacing, Number of marks, Positional reading, Symbols, Brightness, Application, Pointers.

RLC-5. Self-luminous materials: Brief notes covering a few points of practica importance. January 8, 1918. pp. 14.

Unapplied material—General remarks, Growth in brightness for 3 weeks, Decrease in brightness after 3 weeks, Effect of light, Brightness, Fineness of grain; Applied material—Brightness reduced on application, Initial growth after application, Ultimate decrease in brightness; Manufacturers and prices; Relative values of different products.

RLC-6. Notes and recommendations regarding specifications for the illuminating of articles by means of self-luminous materials containing radioactive excitants August 10, 1918. pp. 24.

Basis of specifications, Self-luminous materials, Unit of brightness, Total light Brightness of markings, Summary, A form of specifications, Appendix.

An illustrated report (9 pp., 4 illus.), describing in detail the equipment used by the Bureau of Aircraft Production for the factory inspection of dials, was prepared February, 1919, for and at the request of the New York Navy Yard.

Investigation of Specific Problems

Some of the problems that have been investigated especially for the purpose of obtaining information of military value are the following:

Variation of brightness with the thickness of the material.

Variation of brightness with the width of line.

Effect of immersion in kerosene.

Methods for applying the luminous material.

Brightness required for specific dials, gun sights, targets, indicators, compasses, etc.

In dealing with the last-named problems the Bureau cooperated closely with the parties interested. Usually the Bureau prepared apparatus by means of which an article of the desired type could

be seen with markings of variable or various brightnesses. Then the parties interested examined the article at night and in conference with representatives of the Bureau. In this way the brightness that seemed most desirable was determined.

Certain stencils were designed to use as the rear lights for trucks. This work was undertaken by request for the purpose of determining what form will give the driver of the following truck the most information regarding his distance from the preceding one. The parties requesting the work lost interest in it after the armistice was signed, and the work was not completed.

Equipment for Factory Inspection of Dials

Apparatus was prepared and standardized for the use of the Bureau of Aircraft Production in the factory inspection of luminous dials. A carefully cut stencil of the luminous dial under test is backed by a sheet of milk glass and illuminated from the rear. The lamp illuminating the stencil is moved until the openings in the stencil appear to be of the same brightness as the corresponding markings on the dial. If such a match can be obtained only by moving the lamp farther from the stencil than a predetermined distance, the dial is too faint and is rejected.

Five of these outfits were adjusted and calibrated, and the necessary lamp renewals were provided.

Routine Precison Measurements

Routine precision measurements of the brightness of selected articles were made for several purposes: (1) to enable a prospective bidder to ascertain if a proposed material will meet the requirements; (2) to serve as a basis for the award of contract; (3) to serve as a check on the factory inspection; (4) to furnish information regarding the uniformity of the work; and (5) to determine the permanence of the brightness.

The study of these materials and problems is being continued, and it is expected that in the course of the year a circular treating these materials will be issued by the Bureau.

ROPE, MANILA

This subject will be found under the title "Manila Rope."

RUBBER

Solid Tires

Early in 1917 the attention of the Bureau was called by the Quartermaster Corps of the War Department to the unsatisfactory quality of solid motor truck tires which the Government was

obtaining in the open market. Although these tires were bough from various manufacturers, they all appeared to be about th same grade, which was no better than that of the relatively poo solid tires with which American motor trucks had been equippe during their service on the Mexican border.

At the suggestion of the Bureau samples of all these tires wer secured for tests and analyses, and the results of the investiga tion were correlated with the service rendered by the tires. Th results of this combination of laboratory and field work wer used as a basis for a series of conferences between tire manufac turers, officials of the Quartermaster Corps, and the Bureau o Standards. After a number of such conferences a set of specifi cations was drawn up jointly for solid-rubber tires for moto trucks and artillery wheels, and were first adopted in Novembe 1917, followed by revised editions on December 5 of that yea These specifications were adopted subsequently by the Moto Transport Corps and finally as standard specifications by th purchase, storage, and traffic division of the War Department.

The specifications call for physical tests of the rubber com pounds and fabric, chemical analyses of the rubber compound and physical and chemical tests of the steel base bands. Th Bureau of Standards' methods are specified for making thes tests and analyses. During the period of the war following th adoption of these specifications, inspectors were stationed at th various plants. These inspectors took 1 tire from every 500 an cut out appropriate samples for test. The physical tests of th rubber compound were made at the plant, while the samples fo analyses of the rubber and tests of the base bands were forwarde to the Bureau. Difficulties were encountered in the anylysis o the rubber stock in the tires, because two relatively new com pounding ingredients, glue and gasblack, were being used. Meth ods, therefore, had to be devised for the quantitative determina tion of these two ingredients. It was found that by making modified Kjeldahl determination to arrive at the quantity o nitrogen present, the percentage of glue in the stock could b estimated quite closely. The determination of gasblack was muc more difficult, but a procedure was soon arrived at for this deter mination, which with slight modifications and improvements wa used during all of the tests. The research work on this deter mination forms the subject of technologic papers No. 136 Although much of the routine physical testing at the variou

plants was done by local inspectors, samples were sent regularly to the Bureau as a means of checking their results.

During the year beginning with March, 1918, over 500 complete rubber analyses were made, representing the purchases of 250 000 solid tires having a value of about $20 000 000. It will thus be seen that the War Department through the Bureau's aid was enabled to buy this material on rigid specifications and to have all purchases tested for compliance with these specifications. The tires had to pass tests made at the Bureau before they were finally accepted by the War Department. The result of this cooperative work was a vast improvement in the quality of solid tires furnished the War Department. Through the specifications the department was able to buy goods of standard quality on the basis of competitive bids.

Pneumatic Tires and Tubes

Experience in connection with the development of specifications for and the testing of solid tires as described above led to a similar procedure for pneumatic tires. The results of the solid-tire testing had been so satisfactory that it was deemed advisable to buy pneumatic tires on the same basis. This, however, was a much more complicated and difficult matter, since pneumatic tires are made of so many different types and qualities of materials. Specifications would be required for each particular type, and a decision as to what constituted a good tire was a very difficult one to reach. Manufacturers differ greatly as to the grade of materials they use and as to the methods of manufacture. A great many conferences were held concerning these specifications, and although the work was started in November, 1917, its tremendous quantity and the great differences of opinion involved halted the work temporarily until the outcome of that on solid-tire specifications should be known. The work on pneumatic tires was again taken up during the summer of 1918, and in the following October specifications were issued as a result of the cooperative efforts of the Motor Transport Corps, the War Industries Board, the Rubber Association of America, and the Bureau of Standards.

The details of these tests are in accordance with the Bureau's methods, and references are made in the specifications to the effect that tests and analyses shall be in accordance with the methods in current use at the Bureau of Standards. The tests to be performed on a pneumatic tire are numerous and of a very diverse

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nature. The dimensions of the tire must fall within definite limit the fiber must be of a certain quality, and the different rubb stocks must be subjected to physical tests and chemical analyse Determination of the adhesion or "friction" between the differe layers of rubber and fabric must also be made. As it was nece sary to reduce this testing as far as possible, while still retaining good check on the quality of tires delivered, it was agreed that o tire in every thousand or less should be tested. As soon as t specifications were issued manufacturers commenced to ma tires in conformity with them. Before placing a manufacturer the list for competitive bidding, his tire had to be tested and a proved by the Bureau, and, as a result of this requirement, prac cally all of the larger manufacturers sent two or more tires to t Bureau of Standards for test. The increase in work thus broug about required the use of much more extensive quarters for t rubber and chemical laboratories. Because a large majority these tires were produced in the district near Akron, Ohio, a since there was no further room for expansion at the Bureau, seemed desirable to locate a branch laboratory at Akron. As t result of an agreement between the University of Akron and t Bureau, suitable rooms for this work were fitted up in their chem cal laboratory. The funds for the equipment were made ava ble by the Motor Transport Corps, and the resulting laboratory w well equipped to handle the routine analytical work necessa This work was so largely curtailed by the singing of the armisti that the laboratory was never used to its full capacity. It w expected that should the war continue, the Government would b about $5 000 000 worth of pneumatic tires a month, neces tating a laboratory force of 15 chemists to do the analytical wo called for by the specifications. As in the case of solid tires it w the intention to station inspectors at the factories to secure sa ples and do the physical testing, their results to be regula checked by figures obtained on duplicate samples sent to t Bureau.

Supplementing the specifications for pneumatic tires were spe fications for inner tubes. The tests of tubes were handled in respects in the same way as pneumatic tires, in nearly all cas manufacturers making both tubes and tires.

Since the specification plan for pneumatic tires was put in effect at about the time of the signing of the armistice, the full r sults expected were not attained. There is every indication th

had hostilities continued, the results from this work would have been as satisfactory as those obtained in connection with solid tires.

Gasoline Hose

The preparation of specifications for a large number of parts used in the construction of airplanes formed some of the earliest work of the standards committee of the Society of Automotive Engineers in cooperation with the Aircraft Production Board. Among other things were included specifications for rubber tubing to conduct gasoline from the tank to the engine of an aircraft. Before specifications could be written for such a tube, considerable experimental work had to be done to determine whether rubber was suitable for this purpose, and if so, what kind of rubber compound and what type of tube construction would be most satisfactory. The Bureau cooperated with both the Aircraft Production Board and the Society of Automotive Engineers in carrying out this work. The Bureau's part consisted in the laboratory testing of various types of tubes as they were submitted by manufacturers. The type developed as a result of this work was made up of a combination of rubber and fabric containing a metal spiral reinforcement in the center of the tube, which prevented the tube from closing because of the distortion of the inner rubber by absorption of gasoline. Specifications drawn up for this type of rubber gasoline hose were used as a standard by the Aircraft Production Board.

Oil-Proof Packing

The Ordnance Department needed a special oil-proof rubber packing for the recoil mechanism of a particular type of gun. The French had been using a rubber packing called "Dermatine" in a similar gun, and this proved to be fairly satisfactory. As the Ordnance Department was not satisfied with the packings originally submitted by manufacturers samples of Dermatine packing were obtained from France and were tested at the Bureau. Samples of Dermatine obtained through the Ordnance Department, together with the Bureau's analysis of the material, were furnished to various manufacturers, who then carried out research work of their own and submitted samples for test. These were tested in a practical way by the Ordnance Department, while a check chemical analysis was made in each case by the Bureau. As a result of these tests a certain product was picked out as the most satisfactory, and this was then supplied to the department, the

individual deliveries of packing being checked by chemical analys made at the Bureau of Standards.

Insulated Wire

Throughout the period of the war the Bureau made physic tests and chemical analyses for controlling the quality of insulate wire and cable, particularly submarine cable which was bei purchased under specifications issued by the Panama Canal an the torpedo depots of the Coast Artillery Corps of the Arm A joint committee on the analysis of rubber insulation, comprisi members of the American Institute of Electrical Engineers, t American Society for Testing Materials, and the Bureau of Stan ards, was requested by the Navy Department to furnish a s of specifications with details of test methods for a 40 per ce rubber compound for insulated wire. The specifications recon mended by this committee were adopted by the Navy Departme and later by the Signal Corps.

Mechanical Rubber Goods

Rubber hose of different kinds, including that used for stea water, air, etc., together with miscellaneous rubber goods, such belting, valves, and packings, commonly classed as "mechanic rubber goods," were investigated by the Bureau at the request the War Department, with the object of developing standa specifications for materials of this sort to be used as a basis award in the purchase of supplies for military purposes. T methods followed in investigating and correlating the physic and chemical properties of the various kinds of rubber goods h for the most part previously been developed at the Bureau connection with similar work for other Government departmen In addition to chemical analyses to determine the percentage rubber present and its quality, physical tests were made to dete mine the quality and strength of fabric and the strength, stret and elasticity of the rubber as an indication of the correctness vulcanization. A comparative study was made of vario samples in each of the numerous classes as a means of judging t excellence of the fabrication and when practicable the materia were subjected to conditions approximating those of service, a in some cases accelerated aging tests were carried out to estima the relative life of the rubber compounds used. As a result these laboratory investigations and of numerous conferences wi manufacturers and representatives of the War Departmen standard specifications have been adopted for practically

miscellaneous rubber goods used for military purposes, and these specifications have been issued by the purchase, storage, and traffic division of the War Department as one of their catalogues. In all of the above-mentioned work the complete laboratory equipment at the Bureau, such as the small rubber mill (Fig. 30), was of great assistance in the prompt handling of the investigations.

Rubber Jar Rings for Canning

It is perhaps not generally known that a very important item in connection with the matter of food conservation is the subject of rubber jar rings. At the request of the States Relations Service of the Department of Agriculture the Bureau cooperated in the production of standard specifications for jar rings in order to establish a standard of quality for use by the public and to eliminate the many inferior brands of rings which have been the cause of extravagant waste as a result of food imperfectly preserved. The method adopted by the Bureau was to investigate the physical and chemical properties of the various grades of jar rings on the market and to compare the results obtained with the known behavior of rings in service. It was found that of the many different grades of commercial rings obtainable, those having certain physical properties that are easily measurable may be depended upon to give satisfactory results. Specifications including a series of simple tests and measurements were written by the Bureau and are now published by the Department of Agriculture and recommended for use by the public.

Druggists' Supplies

At the request of the General Purchasing Office of the Field Medical Supply Depot of the Army, an investigation was conducted on a number of rubber articles classed as druggists' supplies, such as rubber hospital sheeting, hot-water bottles, rubber tubing, etc. Physical and chemical tests were made in accordance with the Bureau's standard procedure for such materials, and the award of contracts for hospital supplies was made on the basis of results obtained.

SAFETY STANDARDS FOR MILITARY INDUSTRIAL ESTABLISHMENTS

In 1917 a field inspection of the military and naval industrial establishments was made through the initiative of the United States Employees' Compensation Commission. This field inspection resulted in the submission of a number of recommendations

for increasing the safety in the arsenals and navy yards. Amon these was a recommendation that a safety engineer be appointe for each industrial establishment in the Army and Navy. As result safety engineers were appointed by the War and Nav Departments and stationed at various arsenals and navy yar for the purpose of assisting in accident prevention.

At the time of appointment of the safety engineers an organize effort was made in the Federal industrial establishments to redu accidents, but no standards for the methods of guarding and f material specifications for such guards were available in either t War or Navy Departments. It was accordingly necessary effect an organization by which this work of drawing up safet rules could be accomplished.

The safety engineers held conferences at Washington November 14 and 15, 1917; at Brooklyn on January 15, 191 and at Norfolk on March 14 and 15, 1918, and invited represent tives of the Bureau of Standards to be present. Committees we appointed to draw up safety rules and the Bureau was asked cooperate with these committees in perfecting and codifying t rules. For this purpose, representatives of the Waterto Arsenal and the Boston Navy Yard were detailed to the Bureau Standards for several weeks in the spring of 1918. Prelimina drafts of these safety standards were distributed for criticism a suggestions and after final correction were adopted by vote the safety engineers. Illustrations were prepared and the wh submitted to the officials of the War and Navy Departments f formal approval and promulgation. These standards have n been published by the Bureau of Standards.

The safety rules cover the following subjects: Building constru tion, crane construction, elevators, fire appliances and equipme toilets, wash rooms and locker rooms, power plants and pri movers, power-transmission apparatus, machine guarding, remot control apparatus, head-and-eye protection.

Each of the codes represents the collection in codified form of t best existing methods and practices then in vogue arranged in form to afford easy reference. Nothing original is claimed f them, although considerable new material has been added.

Arrangements were made whereby the safety engineers were prepare and submit to the Bureau suitable illustrations for ea of the codes. At the time the armistice was signed, illustratio for five of the codes had been received.

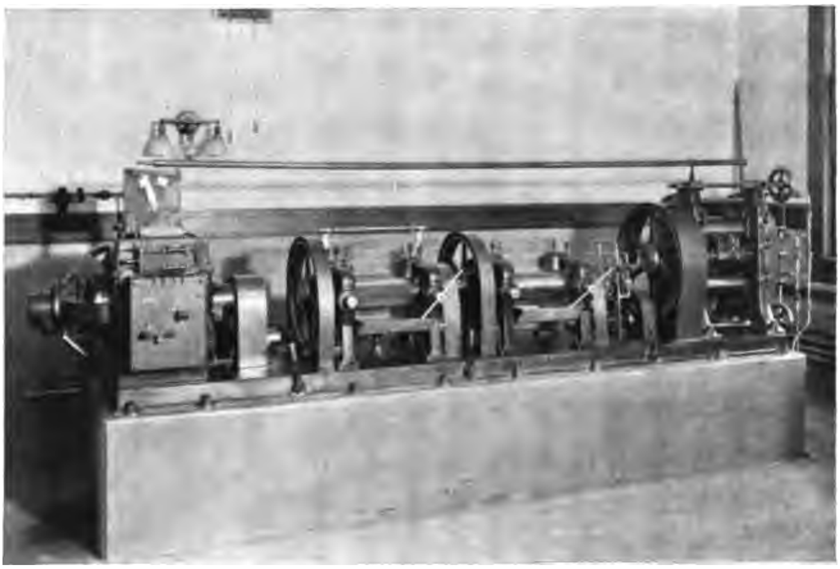

FIG. 30.—*Small experimental rubber mill*

This mill permits the Bureau to study the processes employed in rubber making. During the war rubber was employed on a vast scale for tires, hospital supplies, etc.

FIG. 31.—*Sound-ranging apparatus used to determine the position of a gun by measuring the time at which the sound wave caused by the gun's discharge reaches successive points*

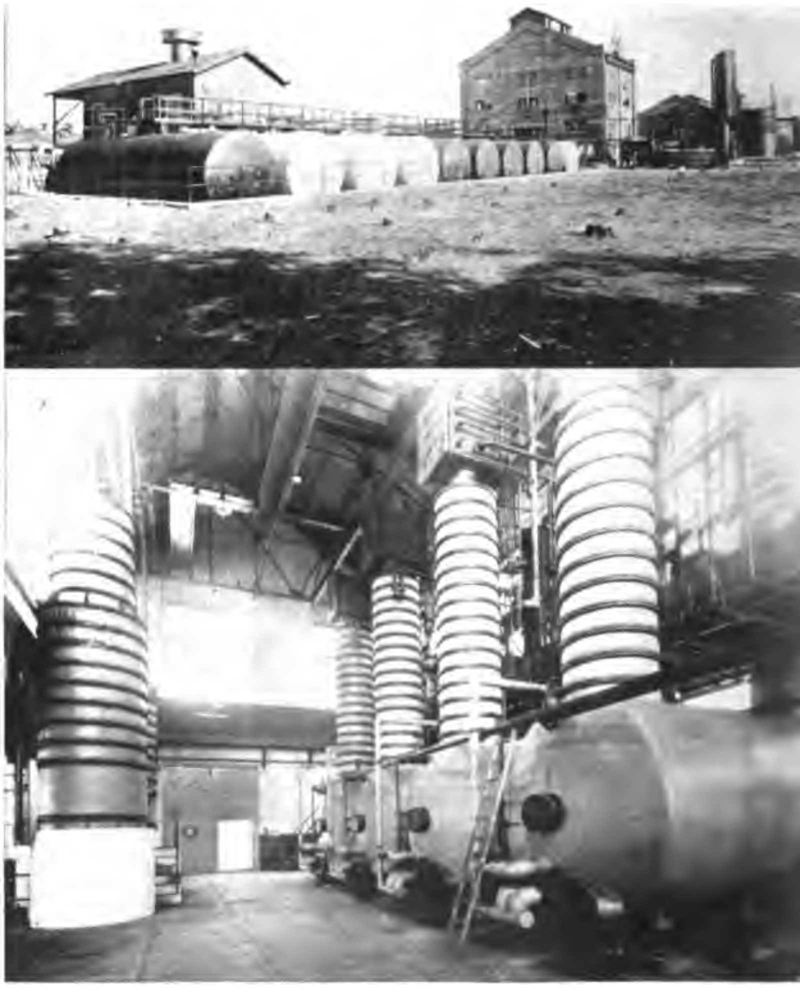

FIG. 32.—*Exterior and interior views of plant for the recovery of toluol from th manufacture of illuminating gas*

Large quantities of toluol were needed in the manufacture of explosives, and the Bureau investi gated the problem of recovering toluol without impairing the gas furnished

The preparation of these safety rules involved in some cases tests and investigations of the devices on the market and of the properties of the material employed for protection. This was notably the case in connection with protection of eyes of workmen from flying particles and from injurious radiation, where it was necessary to investigate the transmission of the different kinds of glass, especially for ultra-violet radiation, and to test glass of various kinds with respect to its ability to resist blows.

A widespread demand that these Federal standards be made available for general use has resulted in the Bureau undertaking to elaborate them and more fully perfect them from the standpoint of general application and mandatory enforcement by State and municipal officials. It is expected that this work will result in the development of a series of national industrial safety codes.

SEARCHLIGHTS

The high-power search lamps have acquired tremendous importance in the last few years. Few data, however, are on record regarding some of the fundamental characteristics of these search lamps or bearing upon some of the more important problems of searchlight illumination. An investigation in cooperation with the Engineer Corps of the Army was carried out, using the combined facilities of the colorimetry section of the optics division and the photometry section of the electrical division of the Bureau. This work is briefly described below.

From data collected by the Bureau, two distinct types of distribution appear: That in the medium-intensity arcs resembles a "rose" distribution; that in the high-intensity a "cardioid" distribution.

The development of high-intensity arcs by the use of specially prepared carbons has resulted in the production of a light which is very blue relative to artificial incandescent sources. In a general investigation of searchlights, including the effectiveness and suitability of their illumination for various purposes, it appeared desirable to have at least approximate quantitative data on the color of this light.

An investigation was made by spectrophotometric and special colorimetric methods, and a report was issued to the Engineer Corps and others, January 23, 1919. Another report was made to the American Physical Society, April 25, 1919, and wns published in the Physical Review.

The result of these investigations may be roughly summarized by saying that the color of the light from these arcs is approxi-mately equivalent to the light of the noon sun in Washington although relatively more intense in the blue-violet.

The diffusion or scattering of light along the path of a searchlight beam is very important from several standpoints. The diffusion of the light out of the beam decreases the intensity of light fallin upon the target. This diffused light limits the visibility of th target for an observer near the search lamp who must look throug and along the beam. On the other hand, this diffusion of the ligh along the beam makes possible the use of the searchlights as land marks for military and other purposes, and also facilitates the train ing of the beam in a given direction, particularly when combine action of two or more search lamps is desired.

Measurements from various directions have been made of th brightness of the path of the beam due to the diffusion of the ligh by the atmosphere. The percentage of polarized light in the dif fused light has also been determined.

In order to make any conclusions as to the size and distanc of a given target that may be seen in a searchlight beam, there i demanded some knowledge as to what is the minimum difference o brightness that the eye can detect. Laboratory experiments wer made to collect data upon the contrast sensibility of the eye unde conditions closely simulating those under actual searchlight illumi nation. Very definite results have been obtained.

In connection with the testing and use of search lamps, the ques tion of how much light is lost as the beam penetrates the atmos phere must be considered. It is important to know what th transmission of the atmosphere is when tests are made at grea distance from the search lamp.

Very meager definite data exist upon the transmission of th atmosphere under all weather conditions—clear, hazy, foggy, rainy etc.

It is important also to have a knowledge of the relative trans mission for different-colored lights.

A method has been devised to procure relative data on the trans mission of the atmosphere throughout the spectrum, and som observations have been made for a clear atmosphere, for one o rather high humidity, and for rains.

These data are not only valuable for the searchlight enginee but are important also in aerial and in other photography and t the illuminating engineer interested in automobile head lamps, etc

A chart has been made showing where all losses of light in the search lamp take place, and their magnitude from the moment the current flows through the arc to the time that the beam impinges upon the target.

A physical photometer was constructed for use in connection with the photometry of search-lamp arcs. On account of the high intensity of the light from arcs, they are admirably adapted to the application of such an instrument.

SOUND-RANGING APPARATUS

Introduction

The process of locating a distant or concealed piece of artillery by means of the sound waves produced when the gun is fired is a new and very important development of the present war. Let us assume that a gun is fired at a position which we may call 1. This gives rise to a sound wave that passes out in all directions. If now, we have an instrument similar to a telephone transmitter located at each of three different stations 2, 3, and 4, which may be selected more or less at random, but whose positions are known, it will be evident that the sound wave will, in general, arrive at these stations and affect telephone transmitters at different times. If wires are brought from the telephone transmitters to the central station located at any convenient point and connected to a telephone receiver, the sound of the gun would be heard successively as the wave front arrived at each station and the intervals of time between sounds would be a measure of the differences in distance from the gun of the various stations. It has been found possible to provide apparatus which will record the instant of arrival of the wave at each station and so afford a measure of the time intervals between the arrival of the sound at the several stations. The principle is, therefore, very similar to that of a telephone system except that a recording apparatus is used instead of the usual telephone receiver. The time intervals having been measured and the locations of the stations 2, 3, and 4 being definitely known, it is possible that any one of a variety of methods will locate definitely the position of the gun. This is the fundamental principle of sound ranging which has been worked out in several practical embodiments used by the French and British services.

The principle of sound ranging can be easily understood if we consider that a sound wave passing from a gun has a wave front which is circular in form. In due time this will reach the first

listening station, which we have called 2. A short time later th
sound wave will reach station 3, and still later station 4. If now
we draw a circle about point 3, tangent to the circle of the wav
front through station 2, the radius of this circle d_1 will be th
distance traveled by sound in the time interval between the ar
rival of the sound wave at stations 2 and 3. Similarly, the radiu
d_2 represents the distance traveled by sound in the interval be
tween the arrival of the sound at 2 and 4. Since the velocity o
sound in air under given conditions is definitely known, if we hav
determined the relative time of arrival of the sound wave at th
three stations, the distance d_1 and d_2 can be directly calculated
As an illustration of the method of determining the gun position
let us consider that the distances d_1 and d_2 have been determine
as above stated. Then let us draw a circle about the point
with radius d_1 and another about the point 4 with the radius d
It is evident that the problem is now the familiar geometrical on
of finding the center of a circle which passes through the give
point 2 and is tangent to two given circles drawn about the point
3 and 4, and having the given radii d_1 and d_2, respectively. Th
solution of this problem has been worked out in a variety of way
both graphically and analytically.

In actual practice the determination of the position of the gu
is by no means as simple as outlined above. The velocity c
sound varies with the temperature and humidity of the air, an
the position of the wave front at any time is affected by the direc
tion and velocity of the wind. All these variable factors have t
be observed at frequent intervals and corrections applied. Fur
ther, even if only one gun is fired, three distinct sounds are pro
duced as a rule; one due to the firing of the gun, another due t
the passage of the projectile through the air which is very pro
nounced when the velocity of the projectile is much greater tha
that of sound, and the third which may be produced by the explo
sion of the shells. These sounds, in general, do not reach th
recorder in the order mentioned above. It is necessary to dis
tinguish between these if a correct solution of the problem is t
be had. Further, it will often happen that a number of guns ar
fired so nearly at the same time that the number of sounds pro
duced by all of them will be recorded on the same portion of th
chart, and it often becomes necessary for one to distinguish be
tween the record produced by firing the gun and those produce
by the shell, but it is also necessary to determine which portion

of the record received from the different stations belong to any particular gun. It will thus appear that in actual practice sound ranging involves a rather complex practice. However, the apparatus and methods of use have now been developed to such a high degree that it is possible under average practical conditions to determine all the information referred to above and make the necessary corrections for the variable factors involved, and determine quite closely the position of the gun within one to two minutes after the gun is fired.

Upon the entrance of the United States into the war, the matter of sound ranging was brought to the attention of this Government by the French Scientific Commission. This commission strongly urged that an investigation of the matter be taken up at once for the purpose of determining upon a system to be used by the American Army, either by selecting from the systems already in use the one best adapted to the purpose of sound ranging, or developing a new and improved system. The portion of this investigational work which has been done at the Bureau of Standards forms the subject of the present report.

The work of the Bureau of Standards on sound ranging was taken up following a conference held in the office of the Council of National Defense. This conference was attended by the officer who had been placed in charge of the sound-ranging work, a member of the National Research Council, two officers representing the French Scientific Commission, two members of the staff of the Bureau of Standards, and others. At this conference the sound-ranging problem was discussed in its general aspects and an agreement was reached whereby the War Department's staff, then located at Princeton, would take up an investigation of the Dufour and Bull systems, and the Bureau of Standards would make a study of the Cotton-Weiss system and the so-called T–M system.

The work of the Bureau in this connection was preceded by a careful study of various descriptions of sound-ranging apparatus and of reports bearing on its operation which had been placed at the Bureau's disposal by the French Scientific Commission. Two sets of apparatus were designed and constructed, one embodying the Cotton–Weiss system and the other the T–M system, and after a little preliminary work in the laboratories of the Bureau of Standards these two sets of apparatus were taken to the Sandy Hook Proving Ground for field tests.

Preliminary Work

The first of the two types of apparatus investigated by th Bureau, the so-called Cotton-Weiss system, is a nonrecordin system which was used to a considerable extent on the Frencl front quite early in the war, but, according to the Bureau's infor mation, was after a short time used only in a few special cases In this system two sets of apparatus are used at a distance of kilometer or more apart, each set having two receiving station located perhaps 100 m distant from each other. An indicatin device on each set shows the difference in time of arrival of soun at the two listening stations. These differences in time deter mined at the two separate locations afford sufficient data fo calculating the approximate position of the gun.

In the second type of apparatus, the so-called T–M system three or more receiving stations are used, each of which is con nected by a pair of wires to a central recording station. At th recording station there is an oscillograph or galvanometer actuate by changes in current on the lines to the receiving stations, an the pointers of the oscillograph trace a line on a smoked pape tape run at uniform speed. The difference in time of arrival o the sound from the gun at the various receiving stations is deter mined by measurements of distance on the smoked paper, an these differences in time determined for three or more station provide data for calculating the position of the gun.

Complete sets of both Cotton-Weiss and T–M types of apparatu were constructed and taken to Sandy Hook, where several day were spent in making tests. During the same period the Wa Department's staff at Princeton made similar tests on both th Dufour and Bull types of apparatus. As a result of these earl tests it was decided at a conference between representatives o Princeton and the Bureau to abandon for the present furthe development work on the Cotton-Weiss system, chiefly becaus it appeared that the recording types of apparatus presented marke advantages over the nonrecording Cotton-Weiss system.

The first series of tests with the T–M apparatus did not yiel satisfactory results, due partly to troubles with the microphone and partly to a lack of sufficient sensitivity in the oscillographs A sufficient number of tests were made to bring out fully th weaknesses in the preliminary design, after which the apparatu was brought back to the Bureau of Standards and remodeled Improved microphones were constructed, and a new type of oscil-

lograph which will be described in detail later was developed, and the apparatus was again taken to Sandy Hook for test. During this series of tests the entire apparatus worked in a very satisfactory manner and three receiving stations were laid out roughly on rather short base lines, and some actual ranging tests were made. These ranging tests, although only partially satisfactory, were very instructive and served to bring out certain minor defects in the apparatus which required elimination. This second series of tests revealed the desirability of conducting rather extensive studies of several phases of the sound-ranging problem, and a series of such investigations was planned and carried out by the Bureau prior to designing and building the improved sets, which were finally developed. A brief account of these experiments is given below; detailed descriptions of the apparatus and methods developed and used by the Bureau will be given later.

Brief Review of Investigations of Various Phases of the Sound-Ranging Problem

The preliminary work showed that the original form of T–M microphone was not sensitive enough for effective practical use. Furthermore, the resistance of the microphone buttons is so low that a relatively low-line resistance is necessary in order that the latter will not be too large in comparison with the frame. In general, it is not practicable to secure this low-line resistance by using heavy wire because of the bulk and weight of line equipment as well as the cost of the wire. The Bureau set to work on the problem of developing a more sensitive microphone and one which could be used with a relatively high-resistance line wire. These objects were finally accomplished by using a four-diaphragm microphone, each diaphragm having a separate microphone button attached to it. These four microphone buttons were connected electrically in series, thus giving a total line resistance of four times that of a single button. This arrangement was found to work very satisfactorily, and it was found possible to give all the sensitivity that was desired and still use a line resistance of the order of 1000 ohms.

Another phase of the microphone problem that was given special attention was that of making the microphones selective to the muzzle wave. It was found desirable to secure records that are free from the effects of the bow wave, or so-called crack, due to the velocity of the projectile moving through the air. A record with these effects eliminated is greatly simplified and rendered much

easier of accurate analysis. The Bureau finally developed a microphone which contained extremely high sensitivity to the muzzle wave, but which would not give any appreciable response to the crack even though the shell was so near the microphone that the crack of the bow wave was many times greater than that of the muzzle wave. The microphones can be very readily rendered sensitive to the crack for special work, as occasion requires, without any change whatever in construction of the microphone; that is, a given microphone can be changed in the field to one very sensitive to a crack or to one which is unresponsive thereto, as may be required.

A microphone was finally developed which was found to be very much less sensitive to wind pressure than the original T–M microphone.

The original T–M oscillograph was of the moving-iron type, and the Bureau's preliminary work indicated that it was not one adapted to this work. Accordingly, a moving-coil oscillograph was developed, using a very short pointer and an electromagnet which gave a surplus of sensitivity for all practical purposes. This oscillograph has proved very rugged and reliable under service conditions, and it is believed to fully meet the requirements of the sound-ranging service.

In the original apparatus used by the French Army the smoked chart was fixed after the record had been removed from the recorder by laying an additional strip of paper over it and passing it through a number of rolls. This was found to give rather unsatisfactory results, such records being poorly fixed and rather easily smudged. Another method used for some time consists of dipping the smoked record in a thin solution of shellac and then permitting it to dry. The objections to both these methods were chiefly the danger of losing the record in handling, due to accidental smudging, and also the time elapsing before the record was available for study. This was important, particularly in the case of the shellac fixing. After considerable experiment the Bureau developed a method of fixing by causing the tape to pass over a drum which applied melted paraffin to the inside of the tape, which promptly soaked through and fixed the record on the other side. This was made a process continuous with the making of the record itself, so that the record came out of the recorder all fixed and ready for use. The danger of losing the records due to smudging and handling was thus entirely eliminated and the

record was immediately available for analysis upon coming out of the recorder. This method of fixing has proved eminently satisfactory in practice.

In addition to the above a large amount o. exper.mental work was done in connection with the design of a suitable type of transformer for the recorder, the development of timing devices for accurate recording of time on the record, and, particularly, much attention was given to methods of procedure in sound ranging. A number of methods of analyzing the charts, working up the data, and calculating the position of the gun, including the making of various corrections for wind, temperature, and humidity, were developed in connection with this work.

The final form of this apparatus (Fig. 31) was completed and went to France in the autumn of 1918, arriving there only the day before the armistice was signed, so that opportunity was not afforded for trying it out under actual war conditions. The apparatus has been very thoroughly tested, however, at the Naval Proving Ground at Indianhead, Md., and its success was fully demonstrated.

SOUNDS TRANSMITTED THROUGH THE EARTH

When the French Scientific Commission visited this country in the spring of 1917, they brought with them various devices for the detection of sounds which were transmitted through the earth. These were particularly valuable in listenting for mining operations. In October, 1917, the Engineer Corps and the Bureau undertook to develop these types of apparatus for the use of our troops abroad.

Two types of apparatus for detecting earth vibrations, of high frequency (sound waves through the earth) have been studied. The first type of apparatus is entirely mechancial and is called thı geophone (Fig. 33); the second type is electrical, and is called a seismomicrophone.

Geophone

The geophone consists of a heavy mass suspended by two diaphragms inside of the case with thin air spaces above the upper diaphragm and below the lower diaphragm. One of these air spaces is connected by rubber tubing to one of the ears of an observer. If the geophone is placed firmly in contact with the earth, an earth vibration causes the case to move with the earth, but the steady mass due to its inertia and its suspension tends to

remain at rest, so there is a relative displacement between the case and the steady mass. This displacement sets up in the air space alternate condensation and rarefaction, which are transmitted through the rubber tubes to the ear, thus producing the sensation of sound.

Two geophones are usually used, one being connected to each ear of the observer. Then, if the two geophones and the connecting tubes are identical, they become listening devices by which the ear can detect the direction of the sound through the earth in the same way that the direction of sound coming through the air can be detected.

The geophones which were brought by the French Commission were very sensitive, but it seemed worth while to see if a still more sensitive instrument could not be produced, especially one which would more faithfully reproduce the character of the sound which was received. Accordingly, a considerable number of instruments were constructed, using different sizes of instrument, methods of suspension, kinds of case, sizes of tube running to the ear, and practically every other factor which could be readily varied. The resultant instruments were tested in dugouts, which were constructed to simulate as far as possible actual field conditions. A standard source of sound was used and the results carefully collected. The tests of the apparatus constructed as a result of these investigations showed that it was appreciably better than the French instrument on which it was based and was also more convenient to use.

Seismomicrophone

The seismomicrophone or telegeophone consists of a microphone which is attached to a geophone. However, a number of modifications can readily be introduced, so that the finished instrument does not resemble the geophone.

As the microphone is a very sensitive instrument, it is not necessary to use as large a mass as in the case of the geophone. In fact, an ordinary microphone to which is attached a small weight gives quite satisfactory results.

The seismomicrophone can not readily be used for determining the direction of sound, as the binaural effect is not satisfactorily transmitted through a microphone. However, it is a very useful instrument in mining operations. The complete outfit which was developed for the U. S. Army was lighter and more compact than that used by the French.

FIG. 33.—*Instrument for detecting sounds transmitted through the earth*

Listening apparatus of this kind was developed to such a point of perfection that toward the end of the war scarcely any mining operations could be carried on without detection

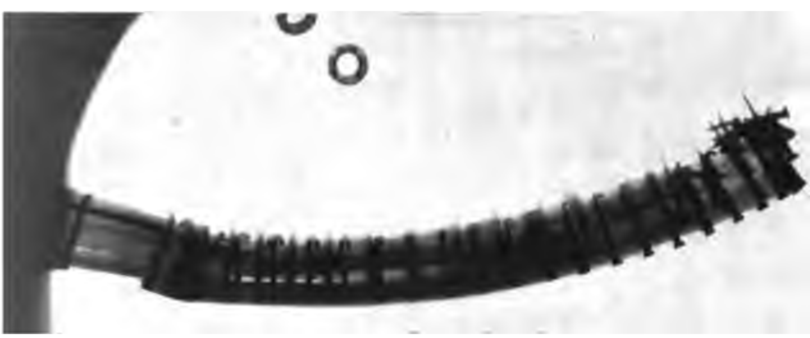

FIG. 34.—*Print of radiograph of a repaired shoe*

One of a series taken for the purpose of studying the clinching of nails by different types of soling machines

FIG. 35.—*Steel artillery wheel tested to destruction in the large Emery precision testing machine*

This illustrates only one of the thousands of physical tests of materials which the Bureau carried out for the Army and Navy. The design of the wheel used on the Army's "Class B" motor truck was based upon a complete wheel investigation conducted at the Bureau

It was reported from the front that the development of listening apparatus on both sides reached such a high standard that mining operations could be carried out only with the greatest danger to those concerned. Sounds of digging, picking, and the like, could be detected at such a distance as to give ample time for the development of counter measures. Hence, mining operations very largely ceased along most parts of the front before trench warfare was abandoned. In some places, however, it was still found possible to carry on mining operations where soil conditions were such as to prevent effective counter measures.

The instruments described in this report were used very little on the front, though the fact that they were available had important bearing on the conduct of mining operations.

SUBMARINE DETECTION

Means for Visual Detection

Immediately after the United States entered the war, the detection of the submarine was perhaps the most pressing of all problems. In the course of time various means of detection were developed, some of them of a highly technical and complicated nature. At the outset it appeared that the simplest means of detection—viz, sighting the submarine or its periscope—should not be neglected but developed to its highest possible efficiency. The National Research Council appointed a committee, on which the Bureau of Standards was represented, to consider and make recommendations on this subject, in particular in regard to aids to vision, methods of observation, and development of the lookout service.

The report of this committee was prepared at the Bureau and transmitted to the National Research Council on July 23, 1917. A supplemental report was issued on October 6 of the same year. Among the recommendations contained in these reports the following aids to vision were called to the particular attention of the council as being of undoubted value and capable of practical application: (1) Goggles to protect the eyes from top, bottom, and side lights; (2) orange glasses, such as that known as "Corning G-36;" (3) binoculars of low power, large field, and (for twilight and night) highest possible brightness. Recommendations were likewise made as to the organization of the lookout service, with a view to aiding in the prompt detection of the submarine or its periscope.

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TELEPHONE PROBLEMS

Study of the Telephone Situation in the District of Columbia

The extraordinary situation which confronted the telephone company in Washington as a direct and indirect result of the war was called to the official attention of the Public Utilities Commission of the District of Columbia through the company's formal petition for relief, filed November 30, 1917. The size and activities of the Government departments grew by leaps and bounds; many new bureaus were created; tens of thousands of war workers were required; and several military camps were established in and around the District. All this resulted in an enormous and rapid increase in the demand for telephone service and facilities, both local and long distance. In addition, the demand for war workers seriously handicapped the telephone company in maintaining its operating staff. The telephone company petitioned the commission for both traffic and financial relief. The Federal Government was, of course, vitally interested in prompt, accurate, and adequate telephone service.

Under date of December 15, 1917, the Public Utilities Commission formally requested that this Bureau be represented at the hearings. These were held during December, 1917, January, February, and July, 1918. The efforts of the Bureau's telephone engineers were primarily directed to determining the facts in the case and to devising measures for temporary as well as permanent relief.

On March 15 the Postmaster General, through the Secretary of Commerce, requested the Bureau of Standards to prepare a report on the local telephone situation, to include:

1. A digest and analysis of the telephone situation in Washington as brought out in the hearings held up to that time.

2. The relative advantages and limitations of the manual, the semiautomatic, and full automatic systems of telephone.

3. The relative adaptability of manual, semiautomatic, and automatic central-office installations to prompt and economic enlargement.

4. The practicability of "physical connection" and manual systems, especially with reference to long-distance working.

5. An analysis of the methods proposed for immediate and for permanent relief of the local telephone situation, including comparative investment data, maintenance, and operating expenses.

The Bureau's report, subsequently published as Part II of H. R. Report 379, accompanying H. R. 10337, entitled "Extension of the Telephone System in the District of Columbia," was submitted to the Postmaster General in April, 1918.

More than half of the report was taken up by a rather detailed analysis of the local telephone situation as developed in the hearings. The materials of this section, Part I, which included a number of tables, was grouped under the following headings: Line and station data, Service, Traffic, Adequacy of equipment, Availability of automatic appliances, Revenues, expenses, and return on fixed capital, and Distribution of charges between the Government and public.

In Part II was discussed (1) the relative ability of the manual, semiautomatic, and full automatic systems to handle traffic; (2) the quality of telephone service that might be expected of each system from the standpoint of reliability, accuracy, speed, supervision, continuity, and secrecy; and (3) the relative number of employees required for operation and maintenance for the three systems.

No detailed discussion of the relative adaptability of manual, semiautomatic, and automatic central-office installations to prompt and economical enlargement was possible in this report because of the lack of reliable data and the brief time available for the preparation of the report. Part III was therefore necessarily very brief. Part IV was also brief, the practicability of physical connection between the several systems having been already fully established. In Part V was discussed the telephone company's proposed method for immediate and permanent relief as outlined in the hearings, and there was also set forth in this section a method of relief proposed by the engineers of the Bureau.

The company's plan was in brief the development of its plant through additional equipment of the same type already in use and the corresponding enlargement of its operating force. The method proposed by the Bureau for meeting the immediate needs of the Government contemplated the installation of automatic equipment in the Government departments and independent establishments, beginning with the War Department, where the telephonic demands were greatest, by providing for the handling of interdepartmental business through an automatic switchboard to be located in the main central office, and the enlargement of

the latter so as to permit connecting selected local subscribers responsible for the bulk of the incoming and outgoing Government traffic. By this means the Government's requirements would have been adequately and promptly met through what might be described as a telephone system within the local system.

It was further proposed to undertake a piecemeal conversion of the company's central offices from manual to automatic operation, beginning with those having the largest number of subscribers and the largest volume of traffic.

At the July hearings the experts of the Bureau were on the stand for direct and cross examination relative to the data set forth in the above report and in other exhibits submitted at the request of the commission.

The hearings were adjourned on July 31 without any decision by the commission, whose jurisdiction in the case was terminated, for the time being at least, when the Federal Government took over the telephone systems of the country.

In the meantime the company had acquired control over the situation, and the unexpectedly early termination of hostilities in the following November entirely changed the aspect of the problem.

TESTING MACHINES, CALIBRATION OF

This subject is treated under the title "Calibration of Testing Machines."

TEXTILES

Cotton Fabrics

The assistance of the Bureau of Standards was requested by various purchasing branches of the war organization in the summer of 1917 in the development of methods of dyeing and of testing the various olive-drab cotton fabrics needed. The American textile industry was at that time just recovering from the shortage of colors which had followed the cessation of foreign importations. Supplies of dyestuffs were limited. Many of the fast colors which now again are obtainable were not to be had. Those on the market were not standard either in strength or in quality. The situation favored the use of inferior colors and unsuitable methods of dyeing. The work undertaken by this Bureau at the instance of the War Department is described below under the following heads: (1) Development of test methods; (2) study of dyestuffs by tests of laboratory dyeings; (3) study of mechanical processes by frequent tests of samples from representative dyehouses.

In 1917 the War Department was using test methods which had been adopted when foreign colors were available. These tests were exceedingly severe. The chemicals used included many which are never encountered in either the wearing or the laundering of textile materials. In one test, for example, a sample of the fabric was soaked for several minutes in concentrated hydrochloric acid, in another a sample was given alternate treatment with potassium permanganate and sodium bisulphite, and finally a sample was steeped in bleaching-powder solution. These tests, operated to enforce the use of a fast hydrosulphite vat color formerly sold in this country by a German dyestuff factory, and only recently offered by American manufacturers.

This Bureau believed that tests which do not reproduce the conditions of wear tend to limit the dyer in his choice of colors without advantage to the purchaser, and that moreover they restrict development on the part of the color makers. Accordingly, it was recommended that simpler tests be adopted which should reproduce service conditions and that the tests adopted be rigidly applied. The recommendations of the Bureau were largely accepted.

Prior to the recommending of these tests it was necessary to assemble data as to laundering methods and the expected life of garments and equipment in service. At one stage of the investigation a number of representative fabrics were sent to a Washington laundry to be put through the regular washing process several times. The results were compared with those obtained under the application of the laboratory test methods.

The sulphur colors, which ultimately were universally used in this work, differ more in their properties than is generally recognized. Particularly noticeable is their variation in fastness to light. Certain sulphur colors are so extremely fugitive that dyeings from them fade seriously upon a few hours' exposure to bright sunlight. The good sulphur blacks, on the other hand, are very fast to light. The fastness of the browns and olives varies considerably. The variety of sulphur colors which appeared on the market made it desirable to include a light fastness test in the specifications. Exposure to sunlight is the natural method of testing. Unfortunately such exposure takes several weeks and can not be carried out in a manner which is both fair and reproducible.

Data on the performance of various lights sold for the testing of dyestuffs were obtained from the radiometric section, whose investigations of the nature of the light produced are described in Bureau of Standards Scientific Paper No. 330, and obtained also by comparing the action of the lights with that of sunlight on representative fabrics. The incorporation of a light test in the specifications was followed by a noticeable decrease in the number of samples on which it was necessary to make an unfavorable report because of deficiency in this respect.

The wood colors, such as cutch, can be used to obtain the desired shade for Army fabrics. The shades so produced are quite fast to washing and to light. Unfortunately they are changed by perspiration. Accordingly, it was necessary to incorporate in the specifications tests with organic acids to duplicate the effect of perspiration and to prevent the use of wood colors. Acetic acid was recommended on account of its general availability.

At the request of the office of the Quartermaster General and the War Industries Board, a collection of all the available colors for dyeing the olive-drab shade on cotton was made. From these, small strips of cloth were dyed by following closely on a laboratory scale the directions of the manufacturers. These dyeings were tested carefully, and the test samples were then mounted on cards for easier comparison. The samples were tested for the effect of sunlight and of the dye-fading artificial lights, of washing and rubbing, and of acid, both before and after treatment with the various metallic salts used to increase the fastness of sulphur colors. The cards, containing about 4000 samples, were much used in conferences with representatives of the War Department. They were of special value in that they afforded a ready means of demonstrating the defects of particular dyestuffs. They also showed the necessity of adopting proper methods of after treatment, and were of considerable value in interpreting the results of tests of commercial dyeings made at the Bureau. At the time of the signing of the armistice they were being used to determine whether or not further limitation of the supply of toluene allotted to color makers could be made by the substitution of certain dyestuffs not containing toluene or its derivatives without leading to the production of unsuitable colors.

Cotton military fabrics are commonly dyed in the piece in the continuous machine. This may be operated so as to produce

excellent dyeings with the sulphur colors, or to produce dyeings in which the color is only superficially fixed. Other mechanical dyeing processes can also be operated so as to reflect the skill and care of the dyer. To determine the effect of variations in the speed of operation of dyeing machinery, in the placing and position of squeeze rollers, in the temperature and composition of the dye bath, and in methods of after treatment and finishing, samples from representative mills were frequently tested in cooperation with the inspection division of the cotton-goods branch of the Quartermaster General's Office. Tests of these samples led to the recommendation of certain processes and the criticism of contractors who were producing faulty material. In general, the fabrics which were shown by tests in 1918 to be deficient in fastness failed because of defects in the mechanical process of dyeing rather than because of the use of inferior colors.

While engaged in this work the Bureau was called upon for information as to a large number of related topics, such as methods of redyeing garments and the stripping of tailor's clippings for paper making.

Woolen and Mixed Fabrics and Felts

The expansion of the Army following the entrance of the United States into the war was followed by a great increase in the amount and variety of woolen materials purchased. This led to a large increase in the testing work requested of the Bureau. The work included the following: (1) Testing fastness of color; (2) studies of methods of dyeing; (3) determining fiber composition of mixed materials.

Colors for the production of fast olive-drab shades on wool are easy to make in comparison with the colors used on cotton and were available at the time the demand arose. The properties of the colors were also well known to dyers, as the dyestuffs were identical in composition with those which had formerly been imported. The test methods in use in 1917 had been employed by the War Department for several years. They consisted of boiling in dilute-soap solution, boiling in dilute sodium-carbonate solution, and exposure to light. In the summer and early fall of 1918, as part of the general movement toward the standardization of tests and their better correlation with service conditions, the Bureau recommended that the use of the boiling solutions be discontinued, on the ground that they are not generally used in washing woolen material. It was suggested that the use of luke-

warm solutions be substituted, and that in the washing tests emphasis should be placed on the rubbing. Boiling solutions were, however, generally used throughout the war. Their use affords a quick method of demonstrating the presence of inferior dyes.

The light tests were made in a similar manner to those used for cotton fabrics. It was customary to make tests of the fastness to laundering on rather larger pieces than were used for the cotton-fabric tests and to determine simultaneously the amount of shrinkage.

A collection of the dyes used in producing the military shade on woolen fabrics was made and used for the preparation of dyed fabrics. The latter were tested and mounted in the same way as the dyed cotton fabrics and were applied to the same uses.

The bichromate used for mordanting or fixating the wool colors becoming scarce toward the end of the war, a number of experiments were undertaken to determine the feasibility of substituting other mordants. These experiments were not completed, but in general it was found that the bichromate is so superior to other readily available mordants that it would be more wise to attempt to increase the supply of chrome ores than to attempt to substitute another material.

Wool being considerably higher in cost than cotton, it is advisable in the manufacture of certain types of woolen fabrics and felts to mix with it such an amount of cotton as can be used without resulting in diminished usefulness of the finished article. For example, saddle blankets were made for military uses with a cotton warp and a woolen filling. In this way the strength of the cotton yarn was obtained without sacrificing the desirable characteristics of wool for this particular use. Similarly, in the manufacture of felt considerable saving in cost may be made without loss of utility.

Quite a variety of such mixed materials were purchased by the military branches, and a large number of samples were submitted to this Bureau for determination of the fiber composition. After some experimentation a convenient method of manipulation of the customary process of making such analyses, which consists, essentially, in dissolving the wool in boiling sodium-hydroxide solution, was agreed upon and recommended to the War Department for the guidance of inspectors.

Waterproofed Canvas

Waterproofed canvas was purchased in large quantities by various branches of the War Department. The conditions of use were so severe that it was necessary to make a very careful inspection of material for purchase. Practically every manufacturer had a different formula or mechanical process. Waterproofed canvas for military uses must not only be thoroughly waterproof, but must also be resistant to mildew, free from objectionable odor or poisonous material, permanently pliable in cold weather and after prolonged exposure to sunlight, and reasonably cheap. The War Department requested in the fall of 1917 that the Bureau cooperate with the purchasing agents in establishing methods of testing and in selecting the material for purchase.

Most of the methods of testing suggested in the literature on the subject were found to be too lenient. Others did not reproduce service conditions. Two methods of testing for waterproof properties were eventually agreed upon. The first was designed to reproduce the penetrating effect of beating rain. In this test a sample of the fabric was stretched over a wide-mouthed bottle, fastened in place, and subjected to a continued spray at considerable pressure for several hours. As tarpaulins are at times spread upon the ground to protect materials placed upon them from water, another test was used to duplicate this condition. A generous sample of the fabric was formed into a bag, filled with heavy articles, and placed in a pail of water for several days. These tests were found to be quite severe.

To determine the resistance to mildew, strips of the various fabrics were prepared for the tensile-strength machine and then suspended for several weeks in loosely covered jars in which there was a growth of mildew. The jars were kept in a warm, dark, and damp place. After the exposure the strips were cleaned and, except in the cases where the fabric had completely disintegrated, were tested for tensile strength. It was found that the mildew growths could spread over the surface of some fabrics without injuring the fabric itself.

The effect of the probable extremes of temperature was determined by careful inspection of the material after heating for several hours at 45° C, and again while immersed in a freezing mixture.

A number of representative fabrics were exposed to sunlight on the roof for several weeks. It was found that in some cases the waterproofing material was decomposed by the action of light.

It was realized that the construction of the canvas used had an important bearing on the wearing qualities of the finished fabric and a number of samples were subjected to the regular analysis of cotton fabrics carried out by the textile section.

An analysis of the coating material was made on about 150 samples. The materials found included asphaltum, wood tar, drying oils, paraffin, resin, glue, petrolatum, starch, inorganic and organic antiseptics, and various inorganic weighting materials and pigments.

Several ready-mixed waterproofing preparations were offered by manufacturers for use in recoating fabrics. Many of these were analyzed and tested by applying the usual tests to fabrics coated in the laboratory.

An interesting feature of the study of waterproofed canvas was the examination of a number of French, English, and German fabrics obtained through the War Department. Few of these were as good as the average American canvas.

Airplane Fabrics

The Bureau conducted a series of experiments which led to the choice of mercerized cotton fabric of a certain construction as a substitute for the linen fabric employed as a covering for airplane wings used before the war and later unobtainable. In the routine examination of samples submitted for criticism by manufacturers, the Bureau cooperated by making the tests for amount of sizing and freedom from acidity or alkalinity, which were incorporated in the specifications.

It was found in the course of tensile strength determinations and other physical tests that the mercerized yarns produced by various mills differed more than was to be expected from variations in their construction. It was believed that these differences were due to the various mercerizing processes employed. A study was undertaken of the effect of certain changes in the customary process of mercerizing on the physical properties of mercerized yarns. The results of this study will be published.

Cordage

Manila fiber is the best material of its class for the manufacture of ropes. Other fibers which are considerably cheaper do not resist rotting as well as manila and are not as strong. Conse-

quently, the mixture of these fibers with manila in the manufacture of rope is not only fraudulent adulteration, but may lead to serious accidents or the premature lessening of the utility of articles or appliances in which the rope is used. Because of its longer life, manila rope is economical in spite of its higher cost.

Prior to 1917 the use of the inferior fibers was rather common. In that year a test was devised elsewhere for distinguishing between manila and the other fibers. The accuracy of this test was determined by making many analyses, under different conditions, of known mixtures of manila and nonmanila fibers. It was eventually incorporated in the standard specifications for manila rope issued by this Bureau for the guidance of manufacturers working on Government cordage contracts. Reports of the Bureau of Standards certifying to the presence of inferior fibers in rope sold as manila have been successfully upheld in the courts. A number of rope samples were examined chemically for military organizations. (See article on "Miscellaneous Physical Tests.")

Military Textile Equipment, Uniforms, Blankets, etc.

When this country entered the war the facilities of the military departments for the inspection and testing of military textile equipment were rather limited. The facilities of the Bureau were, therefore, made available to the Quartermaster Corps and the Ordnance Department. All of the materials purchased by the last-named department were tested in the Bureau's laboratories, and this work constitutes a very large part of that carried out on military textiles.

The old Army fabrics and specifications covering them were entirely satisfactory, but the shortage of raw materials and manufacturing equipment made the use of substitutes necessary. It was definitely known that the substitution of structure alone would not necessarily duplicate an article, and the Bureau was called upon to devise test methods which could be used to predict the performance of proposed fabrics. The general procedure adopted was to study the old satisfactory fabrics to determine their performance and to compare the submitted fabrics with the results. The tests included the heat-retaining properties, resistance to abrasion, and resistance to repeated stress. As was the case in the design of airplane fabrics, the textile manufacturers in this country and abroad had never constructed clothing materials to have definite properties, and the Bureau experienced considerable difficulty in determining the characteristics of raw stock and

of manufacturing which governed the exact properties previously mentioned. The opposition to the manufacturing of fabrics to meet definite requirements was so great that the Bureau installed a small experimental woolen manufacturing plant to demonstrate the value of such work.

A great deal of valuable information was obtained in determining the heat-retaining properties of materials, and it was conclusively demonstrated that the old theory that cotton is not so warm as wool was entirely wrong and that the heat-retaining properties of any textile material depend entirely upon the manner in which the fibers are arranged. Many lines of possible research were thus thrown open to determine the best combinations of fibers and structures to make Army clothing lighter and more satisfactory than that commonly used.

The study of the wearing properties of Army clothing was centered about an investigation of the resistance of certain textiles to abrasion and to repeated stresses. In one or two cases laboratory methods were checked up by actual performance tests, and here again much valuable information was obtained for use in constructing more satisfactory Army clothing materials.

The information obtained through these military tests may be applied equally well to civilian clothing, and it seems reasonably certain that methods are available which will enable the manufacturer as well as the Government to study more intelligently the characteristics of this class of goods.

The abrasion test is an attempt to reproduce by mechanical means the wear on fabrics received in everyday use. In this test the machine appears to gradually cut, break, and eliminate the fibers from the surface of the fabric until the loss greatly lessens the strength of the material. One of the chief difficulties presented in this test is the lack of an abrader which will offer an even and homogeneous abrading surface at all times, so that each sample will receive the same treatment. The abrasion is measured indirectly by the resulting change in some other property, such as lowering of the tensile strength, or tear resistance, deterioration in appearance, etc.

All of the investigations for the standardization committee of the Director of Purchase and Storage, Quartermaster Department, including chemical and physical testing, were carried out in the textile laboratories of the Bureau of Standards, and the results have been incorporated in the standard specifications.

The section was in direct touch with the manufacturers of American dyes and had available at all times information as to the best way to dye materials to obtain the best results. Records were kept at all times which showed the exact performance of any American dyestuff. Information of this character was frequently supplied the military purchasing departments, and it is believed that the service rendered was of considerable value.

Dyestuff Chemistry

In addition to the work in dyestuffs already described, war work in dyestuff chemistry of quite a different character was undertaken under the direction of the colorimetry section. This is also described in the report on "Chromatic Camouflage."

It is well known that solutions of individual dyestuffs differ widely in light-absorption properties. The spectroscopic examination of light which has passed through such solutions affords a method for the identification of colors. During the war period considerable progress was made in the projected development of a comprehensive method for the identification and analysis of dyes by spectroscopic measurements. To aid in this work the chemistry laboratory contributed about 30 carefully purified dyes, made from purified intermediates by selected processes. The light-absorptive properties of dye solutions are found also in dyed fabrics, films, colored glasses, paint pigments, leaves, flowers, and other colored objects. In the case of dyed fabrics the effect of viewing materials under different lights is so great that the dyer in matching shades must consider carefully the nature of the light under which a fabric will be used.

By extending and applying the principles involved it was found to be feasible to apply the light-absorptive properties of colored bodies to military uses. An example is a method by which signals may be conveyed to aviators by the use of fabrics dyed the color of grass. These, if carefully made, can not be distinguished from grass by the unaided eye at relatively short distances. When viewed through an appropriate color screen, however, the fabric will appear to be of quite a different color from the grass and thus will be distinguished at considerable distances.

To try combinations which were suggested by the measurements of the colorimetry laboratory, it was necessary to dye a number of fabrics and films. For this purpose use was made of the collection of dyes maintained by the chemistry laboratory and, where necessary, dyestuffs were synthesized from the intermediate

compounds. Several well-matched fabrics and films were obtained which when viewed through the proper color screen were easily discriminated. The results of these experiments were reported in detail to the military organizations interested.

TIMEPIECES

Information and Specifications

From the beginning of the war the Bureau of Standards in its work on timepieces performed a valuable service which it was perhaps better qualified to undertake than any other existing agency. For a number of years the Bureau had carried on the investigation and testing of high-grade pocket watches, and the experience thus secured formed an admirable preparation for the drawing up of specifications involved in the purchase of all classes of timepieces.

So far as is known, the Bureau was consulted at least as to certain details of the specifications for practically all of the timepieces which were purchased by the Government during the war. For one year after the United States declared war on Germany, one member of the Bureau's staff served in an advisory capacity to the National Research Council on questions relating to procuring an adequate supply of serviceable navigating instruments for the new Government-owned merchant marine and later gave up his position at the Bureau to join the Emergency Fleet Corporation, so that he might be able to devote his entire time to this one problem.

Chronometers

A particularly important phase of this problem consisted in the securing of marine chronometers or, what was the final outcome of the problem, the obtaining of an adequate supply of acceptable substitutes. At the beginning of the war there were no chronometer factories in America, and the only available domestic source of supply was the local jewelers scattered throughout the country, from whom an exceedingly small number of chronometers were obtainable. Some could likewise be obtained from the British Admiralty. The production of new chronometers is not the work of only a few months, but involves years. The total supply accumulated from all sources satisfied only about one-third of the demand, and the remainder was met by using high-grade American-made watches called "ship watches." These were all tested, and each watch accepted for this service had to pass the rigid performance test adopted by the Bureau.

The Beginning of a New Industry

As has been the case in many other lines, the necessity for the use of watches as substitutes for chronometers has called the attention of the American people to this need, with the result that one of the leading watch manufacturers in this country has commenced the making of marine chronometers. In all probability these will not be placed upon the market for some time, but it is to be hoped that eventually this will become another industry in which the United States will not be dependent upon a sister nation in time of public emergency.

Testing of Timepieces

The amount of routine testing performed by the Bureau has been exceedingly large, since all of the timepieces purchased by the Emergency Fleet Corporation were given their acceptance test here. The timepieces tested for this organization include not only ship watches but also comparing watches and desk clocks. Since many of these instruments were to be used for a purpose requiring special accuracy and because large numbers had to be rejected, this routine work was considered well worth while, even though each test covered about a month and the number of timepieces tested amounted to approximately 15 000.

Stop Watches

The most important work of this section of the Bureau for the War Department was the aid furnished to the Ordnance Department in obtaining a supply of satisfactory stop watches. As stop watches are not made in America, the only ones available had to be imported, and the errors of these instruments in practical use either influenced the accuracy of scientific data or jeopardized the safety of troops. The inspection or acceptance testing of these watches was conducted at the Bureau. The value and necessity of this work will be appreciated when one considers that even with specifications having only moderately close tolerances, the number of rejections for the best types of watches was as large as 7 per cent, while for the poorest type it ran as high as 67 per cent.

Airplane Clocks

When the construction of airplanes on a large scale was first undertaken, practically the only available kinds of timepieces at all suitable for mounting on the instrument boards of airplanes were large, heavy automobile clocks which were not sufficiently accurate to meet the requirements of this class of service. The Bureau, with the active cooperation of one of the leading watch

manufacturers, developed a suitable type of instrument having all the accuracy that was required even under the most adverse circumstances and for which the weight was only a small fraction of that of all known previously existing types. This new design was adopted by the Signal Corps, and, so far as is known by this Bureau, was used to the end of the war without a change in any detail. A peculiar feature of this problem which was admirably taken care of by the manufacturer was that of the proper lubrication of the movement so that the clocks would not stop when exposed to the extremely low temperature met with at high altitudes.

TOLUOL RECOVERY

Preliminary Work, Conferences, etc.

On April 11, 1917, there was presented before the Pennsylvania Gas Association an article urging the attention of the gas industry to the matter of the recovery of toluol from city gas supplies, in order that there might be available for the Federal Government the necessary quantities of tuluol for the production of T.N.T., which is the preferred high explosive for military uses. Discussions on this subject between members of the Bureau's staff and a member of the Gas Institute likewise took place, and the subject appeared to be of such importance that during the remainder of April, 1917, one of the Bureau's engineers made a careful study of British gas journals to obtain information of interest to the American industry. When this work was completed, it was found that the information obtainable, while valuable, was not particularly applicable to similar problems which confronted American gas companies. On May 2, 3, and 4, representatives of the Bureau also took up with the engineering, physical, and chemical divisions of the National Research Council the question of securing by cooperative effort the maximum amount of information on this subject.

As a result of a conference between the chairman of the American Gas Institute's committee on "The Relation of the Gas Industry to the Military Needs of the Nation," and representatives of the Bureau, it was suggested that a committee be organized including representatives of the gas industry, of the Federal Government, and of State and city authorities, to undertake a comprehensive investigation that would make available to the Government the following facts: (1) To what extent toluol could be secured from the American gas works; (2) what procedure would be necessary in order to make this toluol available; (3) what changes in standards would be required in order that

the tuluol be removed from the gas without violation of local requirements; (4) what financial arrangements could be considered acceptable and proper to compensate the gas companies for the service rendered; and (5) what companies would be most available to undertake this work at an early date.

As a result of this decision, the Bureau conferred with a number of agencies and endeavored in every way to render assistance looking toward the necessary readjustments of standards of gas service, elimination of high-candlepower standards, and substitution of heating values in general well below 600 Btu per cubic foot.

Beginning in the latter part of May the Bureau received from several State commissions, city authorities, and gas company officials numerous inquiries on questions relating to toluol recovery and to the adjustment of standards under the existing abnormal conditions of supply of labor and materials.

After consultation with representatives of all the parties interested it was decided to hold a conference on the subject of toluol recovery on July 31 and August 1 and 2 at the Bureau. The three questions for discussion at the conference, as stated in advance of the meeting, were as follows:

1. The recovery of toluol from gas, including the methods and equipment required for such recovery, and various questions of operation, including standards, costs, yields, and other interesting and pertinent information.

2. The extent to which the present costs of material and labor are affecting the gas-company operation, this to demonstrate to what extent the present situation is making necessary changes in existing standards or existing rates for gas apart from the question of toluol recovery.

3. The relative advantage of changing standards instead of changing rates for gas.

During the meeting a general presentation of the need for some relief to gas companies was offered, and some suggestions were made upon the relative desirability of changing the standards for service instead of changing the price of gas to the customers. However, no definite conclusions were reached at this session.

A great deal of time was devoted to the discussion of the need for toluol and suggestions as to the best means for accomplishing its recovery.

On the last day of the conference the State and city representatives, meeting by themselves, voted unanimously to adopt reso-

lutions appointing a joint committee to further investigate the subject, the chairman of the committee being a member of the Bureau's staff.

The Bureau of Standards then undertook to inform itself more fully as to the current practices in the production of toluol from city gas supplies. For this purpose representatives of the Bureau visited a considerable number of plants where this work was being done and secured the maximum amount of information possible in the limited time available. Information was also sought by correspondence with others familiar with toluol practice who could not be met in conference. The information secured served as the basis for the report on "Recovery of Light Oils and the Refining of Toluol."

The preliminary draft of this report was submitted to the members of the special gas committee on September 19, and the first meeting to discuss this matter was held September 24. With the assistance of the committee's suggestions the Bureau revised this report and issued it in mimeographed form on October 15.

Report on Toluol Recovery

This report covered the subject of toluol recovery in a general way and was divided into three parts: Part 1, The technical relation of the gas industry to the military needs of the nation; part 2, Principles underlying benzol and toluol recovery; part 3, Construction and operation of light-oil recovery plants. Part 1 gave a general discussion of the problem and described briefly the various methods used in manufacturing gas; part 2 described briefly the methods used in the recovery of toluol, while part 3 presented in detail the apparatus and equipment of one type of toluol-recovery plant installation. The adaptability of light-oil recovery by small gas plants was also discussed, and the cost of installation and operation of light-oil recovery plants was touched upon. This paper was published in the Gas Age, of November 15, 1917, the Gas Record, of November 14, 1917, and the Journal of Industrial and Engineering Chemistry, of January, 1918. Through these publications the paper reached a large number of persons interested in the work, and in addition the Bureau distributed many reprints to gas companies, State commissions, and individuals. A great many were asked for by the Ordnance Department of the Army and used in connection with its work.

Additional Committee Work

Following the publication of this paper a second meeting of the above-mentioned committee was held on October 22, at which

time it was expected to discuss at considerable length plans for further work and particularly questions relating to the technical features of the proposed toluol contracts between the Government and gas companies. Preceding this committee meeting the Bureau had held a number of conferences with members of the Ordnance Department of the Army, suggesting certain principles bearing upon the question of toluol contracts, and the Bureau had forwarded to the department as a confirmation of these conferences a memorandum outlining certain principles which it suggested as worthy of consideration by the Ordnance Department in planning these contracts.

On the same day (Oct. 20) a member of the Ordnance Department handed to a representative of the Bureau a copy of the outline of the plans of the former organization relating to the contracts for toluol and expressed his willingness that these matters be discussed by the committee two days later. These suggestions emananting from the Ordnance Department were therefore laid before the joint committee at its meeting on October 22.

In connection with the toluol-contract work done by the Ordnance Department the Bureau of Standards was able to be of great assistance. Several members of the gas-engineering staff spent periods varying from a few days to six months acting as technical advisers of the Ordnance Department.

Publications on Toluol Recovery and Gas Standards

During the early part of January, 1918, the need of a publication giving in some detail the effect upon standards of gas quality of the removal of light oil became apparent. Accordingly, a brief résumé was prepared of the standards of gas service then in force in those cities which would probably be considered for the erection of toluol recovery plants. The method of estimating influence of toluol recovery upon gas quality was described, and the following conclusions set forth. These conclusions represented substantially the attitude of the Bureau on toluol recovery.

As a summary of these points, the following suggestions are offered:

1. Eliminate all candlepower requirements now in force, except for the cities where 18 candles or higher has been supplied, in which localities reach an understanding that at least 12 candles will be maintained for a period, say a year, during which time readjustments of appliances and substitution of mantle lamps would be accomplished to such an extent as to justify complete elimination of candlepower regulations.

2. For plants making coal gas (or practically only coal gas) let the heating-value standard be from 550 to 570 British thermal units.

3. For plants making water gas, either alone or as a major constituent, let the heating-value standard be 570 to 600 British thermal units monthly average total heating value, the adjustment being made between these limits according to the economic conditions of operation.

In order to make the conclusions clear and as far as possible, specifically applicable to all the cases in question, there was given in the paper a list of the localities where such changes of standards as are suggested would probably be necessary.

This publication also had a wide circulation and was reprinted in the Gas Age, of January 15, 1918, the Gas Record, of January 9, 1918, and the Journal of Industrial and Engineering Chemistry of February, 1918. In addition to reaching about 20 000 persons, a number of reprints were distributed.

Previous Publications Combined in Technologic Paper

The supply of both of these publications was exhausted early in 1918, so they were combined and published as Technologic Paper No. 117 of the Bureau of Standards, entitled "Toluol Recovery." Much additional matter was gathered, and changes which had been suggested were incorporated.

This paper is in four parts. Part 1 is the introduction which deals with the need for toluol and the scope of the paper; part 2 is practically the original paper on "The Recovery of Light Oil and Refining of Toluol," previously described, but, in addition, contains a number of tables and other data assembled from various sources and presented through the courtesy of the authors; part 3 is a discussion of the relation of toluol recovery to standards for gas service, and is the paper previously referred to as a separate publication; part 4 gives a typical form of contract which the Ordnance Department made with various companies for the operation of toluol-recovery plants in connection with city gas works.

Increased Production of Toluol in the United States

Notwithstanding the great importance of high explosives in the war the necessity for recovery from city-gas supplies of toluol, the base of trinitrotoluol (T. N. T.) was not appreicated in the United States until this country entered the conflict in 1917. Previous to 1914 the production of toluol in the United States prob-

ably did not exceed 500 000 to 750 000 gallons per year. Most of this toluol came from coal-tar distillation, but smaller amounts were prepared by refining the light oils which were removed from coke-oven gas in a few plants. After beginning hostilities the demand for toluol greatly increased, and it was evident that the common sources of this material would not meet the new commercial demands. As a consequence a large increase in the recovery of toluol from coke-oven gas immediately followed, and later the recovery of this constituent from city-gas processes was undertaken as mentioned in the preceding paragraphs.

To give an approximate idea of the magnitude of the industry thus developed, one need only compare the small output of pure toluol in 1912 and 1913 of approximately 500 000 gallons with the probable output for the year 1918. If the war had continued for the entire year, it was expected that the output would have exceeded 20 000 000 gallons, and by the end of the year 1919 it was hoped that the rate of production would reach 30 000 000 gallons. At the time of the signing of the armistice there were 21 Government-owned toluol plants in operation in city gas works, a typical plant being illustrated in Fig. 32, and a number of other plants were nearing completion or were actually ready to begin operation. Practically all of the increase was made possible because of the recovery of toluol from coke ovens and city-gas supplies.

WHEELS, INVESTIGATION OF ARTILLERY, TRUCK, AND AIRPLANE

The Bureau's superior testing facilities resulted in its being called on repeatedly in connection with development and standardization work of various kinds. Among the investigations carried out were three series of tests on wheels, namely, (1) artillery or gun-carriage wheels in cooperation with the Ordnance Department, (2) truck wheels in conjunction with the Motor Transport Corps, and (3) airplane wheels with the Bureau of Aircraft Production. In all cases the wheel manufacturers worked hand in hand with this Bureau in the development work, and it may not be out of place to remark that this cooperation of private interests with the Government was typical of that experienced by the Bureau during the war.

Wheel-Strength Requirements

On all types of wheels the basic requirements are essentially the same. Such vital requirements are (1) resiliency or elasticity,

(2) strength, (3) durability and economy, and (4) lightness. In the war emergency the military authorities found themselves without any reliable comparative data and there was no time for service tests. The Bureau of Standards was therefore called upon to make laboratory tests.

Types of Laboratory Tests

Each type of wheel, for whatever purpose it was designed, was subjected to two tests. The first of these is the radial compression test in which the wheel is supported on a block and stressed radially by applying load through an axle passing through the hub. The second one is the side-thrust test in which the wheel is supported on an axle which is held rigidly with its axis parallel to the line of application of the applied load. The load is applied to the side of the rim of the wheel through a suitable bearing block. The parallelism of these two tests to the stresses encountered by the wheel in service is easily seen. The radial-compression test subjects the wheel to the same form of loading it receives in service when supporting the loaded truck at rest. The side-thrust test parallels the stresses introduced by the skidding or turning of the truck.

Value of Tests

The value of the radial-compression and side-thrust test in determining the efficiency of the wheel in question, on the basis of the requirements outlined in paragraph 2 of this section, is readily apparent. The resiliency or elasticity is determined by plotting the deformations or deflections against corresponding loads and determining the area under the resultant curve. The elastic resiliency of the wheel reported in inch-pounds is taken as the area under the part of the curve cut off by a vertical line through the proportional limit. The strength of the wheel is determined by carrying the tests outlined above to a point where fracture occurs, or, in some cases, only to a load which represents an adequate factor of safety when there is no sign of failure up to that point. Durability and economy can not, of course, be determined in a laboratory test, except in so far as the minimum required weight represents the minimum cost for metal. Lightness, with strength, constitutes the final basis for comparison of various wheels. Elastic resiliencies and ultimate strengths are all reduced for comparative purpose to a unit-weight basis.

Artillery Wheels

The Bureau subjected about six artillery or gun-carriage wheels to a radial-compression and side-thrust test (Fig. 35). These tests were conducted on the Bureau's 2 300 000 pound Emery hydraulic testing machine, as were the tests of the motor-truck wheels described below. Load was applied to a section of the rim midway between two spokes. These wheels were of cast steel, and most of them were about 155 mm tread by 1350 mm diameter, or 6 by 53 inches in size. The Bureau's tests on these wheels were not so definitely a part of a development program as were the motor-truck-wheel test series. However, certain elements of weakness, including defective welded joints, were discovered and comparisons between various manufacturers' products were furnished the Ordnance Department.

Truck Wheels

In designing the class B military truck, the Army found it desirable to develop a metal wheel having the good qualities of all the motor-truck wheels on the market. The laboratory tests of these wheels were conducted at the Bureau.

The wheels tested were made of cast steel, pressed steel, wrought iron, and wood, and by various manufacturers. The metal wheels included both solid and built-up designs. The series included examples of U spokes, tubular spokes, solid spokes, and disk wheels. The wood wheel included in the series had seen some service, but most of the metal wheels came directly to the Bureau from the factory or foundry.

Radial-compression and side-thrust tests were made on each type of wheel, and the elastic resiliency, strength, and deformations were determined. Using the information obtained from these tests, a hollow spoke and rim cast-steel wheel was designed for the Quartermaster's Department (motor transport section), which was called the "composite wheel." This type of wheel demonstrated the value of the laboratory tests by giving satisfactory results in service.

Technologic Paper on Wheels

The results of the motor-truck wheel test series have been published as Technologic Paper No. 150. The results of tests on 21 wheels are given. The deformations of the wheels in the radial-compression tests were recorded for four points on the rim spaced 90° apart. Load-deformation graphs plotted from these data

are given, from which the proportional limit and elastic resiliencies of the wheel are computed. The proportional limits are then divided by the weight of the wheel to furnish unit-weight figures for comparison. The same program was followed in the side-thrust tests.

The Bureau publication gives a photograph of each wheel and a chemical analysis of the material for each metal wheel. Valuable suggestions for use in the design of truck wheels to afford maximum strength and resilience for minimum weight are included.

Unique Stress Analysis of Wheel

In addition to the data determined for each type of wheel, as outlined above, a complete strain-gage analysis was made of one cast-steel wheel with hollow spokes and rim in a radial-compression test. A 2-inch Berry strain gage was used. Deformations were measured in gage lines established on the rim, on the spokes, and on the hub. After the radial-compression test had been finished, specimens were cut from the wheel and tested in tension. The average modulus of elasticity as determined from these tests (28 500 000 pounds per square inch) was used to reduce the strain-gage data to corresponding stresses. From these data graphs (or stress contours) were plotted showing the stresses in the wheel at 48 gage lengths for loads on the wheel up to 60 000 pounds. Due to the short gage length (2 inches), results of great precision were not to be expected, but in this case the results were very satisfactory.

Analysis Aids Efficient Design

Compressive stresses were found in all parts of the rim except the section between the spokes adjacent to the loading block. That section was subjected to tensile stresses by the behavior of the spokes. The only excessive stress in the hub was at the junction of the two spokes adjacent to the loading block, where the tensile stress reached the proportional limit of the material for an applied load of 50 000 pounds. The stresses in the spokes were all less than the proportional limit of the material, except for two gage lines on one spoke adjacent to the hub. There is a possibility that these two gage lines were located at a thin section of the casting.

To the best of the Bureau's knowledge, this stress analysis by use of the strain gage is the first of its kind ever attempted in connection with wheel design. It is believed to afford a profitable line of study in connection with further wheel design. Only

by such a stress analysis can the most satisfactory distribution of the material in the wheel be obtained. Such data allow the modification of a wheel so as to avoid excessive stresses which cause failure in service tests.

Airplane Wheels

One or more each of eight types of shock-absorbing wheels for airplane landing gears were subjected to radial-compression and side-thrust tests in the manner heretofore described. As these wheels are, of course, designed for smaller loads than are the artillery and truck wheels, the tests were conducted on the 230 000-pound emery hydraulic testing machine.

Palmer Wire-Spoke Wheel

Most of the wheels tested were of the wire-spoke type. There were also included samples of disk-type wheels with spring unit rods and wheels with S-spring steel spokes. Partly on the basis of these tests the Bureau of Aircraft Production adopted the Palmer swedge-spoke type of wheel as the standard construction. These wheels, size about 750 mm diameter by 125 mm tread, weight 8.7 to 9.2 pounds, averaged about 3000 pounds ultimate strength in side thrust and 7000 pounds in radial compression. These figures are based on tests conducted at the Bureau on about a dozen Palmer type wheels from four manufacturers.

The average results of the above tests enable the designer to establish a fair criterion for judging the performance of any other wheel under similar test conditions.

The ultimate strength in side thrust for unit weight averaged 355 for five Palmer type wheels tested, and the corresponding ratio of strength to weight in radial compression was 810. These two values can be taken as fair criterions for judging the value of other types of wheels for this service.

Comparison with Early American Wheel

By way of comparison it may be noted that the strength-weight ratio for S-spring spoke wheels was found to be 160 in side thrust and 380 in radial compression; for the spring unit rod spokes with sheet-steel casing, 40 in side thrust and 430 in radial compression; average of two early American type wire-spoke wheels, 255 in side thrust and 820 in radial compression. The Palmer type wheel has a hub which is not placed symmetrically in the plane of the rim, but which gives added strength to resist the side thrust encountered by the wheels and chassis when the plane lands. Elastic-resilience comparisons also showed the relative superiority

of the Palmer type wheel. This wheel was extensively used for equipping airplanes manufactured in England before these tests demonstrated its superiority over other designs and resulted in its general adoption for the use of American-made aircraft.

X-RAYS

Owing to the fact that the X-ray work of the Bureau was not initiated until the summer of 1917, the Bureau was not in a position to be of as much assistance to the military authorities in this field as it would have been had the work been started at an earlier date.

The work done falls under two heads: (1) The study and testing of protective materials; (2) the radiography of various objects. The work included under the second head was strictly of a cooperative nature, the radiographs being taken for the purpose of furnishing to the respective branches of the War Department information regarding the internal structure of specific articles and the applicability of radiography to the examination or inspection of supplies.

Protective Materials

Lead-impregnated materials (glass, rubber, etc.) are widely used for protecting the roentgenologist and the patient from harmful exposure to X-rays. The protection of the roentgenologist, who under war conditions had to work many hours a day in close proximity to the X-ray tube, was especially important.

A study of these commercial materials demonstrated not only that they differed widely in the protection afforded, but that some of them, even the most expensive, were practically worthless, and that all might be improved in quality. Radiographs were taken of various pieces of lead glass. In one case it was found that of two pieces tested, the one casting the denser shadow, while but 3 mm thick and weighing only 2 pounds per square foot, was of a good quality of lead glass, the other glass, 25.4 mm thick and weighing 12¼ pounds per square foot, was practically worthless for X-ray protection. This piece was, however, representative of some of the most expensive glass that was bought by the Bureau in the open market in 1917. It was also representative of some of the glass that was offered to the Surgeon General's Office.

The Bureau advised the Surgeon General's Office and the larger dealers in X-ray supplies of the presence of this fraudulent material, and urged manufacturers to produce material of a better quality than any that was on the market in the spring of 1917. The

response of the manufacturers was most gratifying, and materials of superior quality are now available.

In connection with this work protective materials were tested for the Surgeon General's Office, inspectors of that office were furnished with data by means of which approximate information concerning the quality of these materials could be determined expeditiously by the simple process of measuring and weighing the specimens, and improved supplies were brought to the attention of military authorities

Radiography

At the request of the reclamation division of the Quartermaster Corps of the Army repaired shoes (Fig. 34) were radiographed for the purpose of obtaining information regarding the driving and clinching of nails by different types of soling machines.

Aluminum propellers for airplane apparatus were examined for the presence of internal flaws.

Thin specimens of steel were similarly examined for the Ordnance Department of the Army.

At the request of the Bureau of Aircraft Production the practicability of applying radiography to the inspection of wood was investigated in some detail. Although under suitable conditions radiographs can give much information regarding internal structure, it appears that in the case of unfabricated wood it can reveal but little of importance that can not be detected by a trained inspector. In the case of finished articles, however, it can in many cases yield valuable information regarding the fabrication, information that can be obtained in no other way. For example, in one piece of wooden construction examined it was evident that certain wooden pins had not been driven home.

The radiography of a number of articles of an unpromising nature, such as censored manuscripts, charcoal, etc., was attempted at the request of the military authorities interested. Although the possibility of successfully radiographing these articles appeared slight, the Bureau studied each case thoroughly, using various techniques before giving up the problem as hopeless.

Somewhat similar to the preceding was the attempted radiography of thick specimens of steel. No satisfactory result was obtained either by the use of X-rays or of radium.